APPLICATIONS of PHYSICAL FORCES

THE APPLICATIONS OF PHYSICAL FORCES.

THE MICROSCOPE

APPLIED TO THE STUDY OF CRYSTALS.

See Chapter III

THE APPLICATIONS

OF

PHYSICAL FORCES.

BY

AMÉDÉE GUILLEMIN.

TRANSLATED FROM THE FRENCH BY

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AND EDITED, WITH ADDITIONS AND NOTES, BY

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PREFACE TO THE ENGLISH EDITION.

AS in the former work, *The Forces of Nature,* done into English by the same hands—to which work, dealing with Science pure, the present, dealing with Science applied, is complementary—the endeavour has been made to bring the different subjects up to date. In carrying out this object, both Translator and Editor have received help from many kind friends skilled in various technics.

Amongst those to whom their thanks must be here tendered, are Mr. William Chappell, Mr. Baillie Hamilton, Mr. G. I. F. Cooke, and Mr. Hermann Smith, who have made additions to the chapters on musical instruments; and Mr. N. J. Holmes, who has revised the description of the organ and given permission to publish an engraving and description of his own magnificent instrument. Thanks are also due to the same gentleman for additional information respecting telegraphic instruments; to Captain Abney, who has added some valuable information regarding photographic printing processes; to the Rev. S. J. Perry, who has looked over the description of the instruments used in the study of terrestrial magnetism; to Mr. Aitchison, who rendered assistance in the chapters on the Steam-engine, and to Mr. Glaisher, who has been good enough to make some corrections in the chapters on ballooning.

The kindness of Mr. Stevenson has enabled a reference of some length to be made to the various systems of lighthouse lenses which have been recently introduced.

The Editor is also under obligation to Mr. MacDonald, the Manager of the *Times*, for information regarding the Walter Press and for the use of the woodcut by which its action is made clear; to Dr. Andrews for permission to include in part his account of the principles involved in the construction of the various Magneto-electric Machines; and to Mr. Conrad Cooke for a description of the Electric Light used in the Houses of Parliament.

To Mr. Cunliffe Owen, the Director of the South Kensington Museum, Messrs. Elliott, Shand and Mason, Aveling and Porter, and Mr. Browning, the Editor is indebted for the use of several illustrations.

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INTRODUCTORY CHAPTER.

FRENCH AND ENGLISH SCIENTIFIC UNITS.

IN the varied examinations into the qualities and properties of matter with which Physical Science is especially concerned, certain units of measurement are essential. And it is unfortunate that in different countries these units are not the same. The Metric or French system, however, is now so universally acknowledged to be the best for scientific purposes, that the Editor by the advice of eminent scientific friends has retained it in this work. Its retention renders necessary a few words by way of introduction.

One great advantage of the Metric System over our own is that it is a decimal system: thus, by the simplest decimal system of multiplication and division, we are enabled to perform with speed and ease any calculations connected wtth it which may be necessary; another is that the same prefixes are used for measures of length, surface, capacity, and weight; and, finally, these various measures are related to each other in the simplest manner.

Unit of Length.—The English unit of length is the yard, the length of which has been determined by means of a pendulum, vibrating seconds in the latitude of London, in a vacuum, and at the level of the sea. The length of such a pendulum is to be divided into 3,913,929 parts, and 3,600,000 of these parts are to constitute a yard. The yard is divided into 36 inches, so that the length of the seconds pendulum in London is 39·13929 inches.

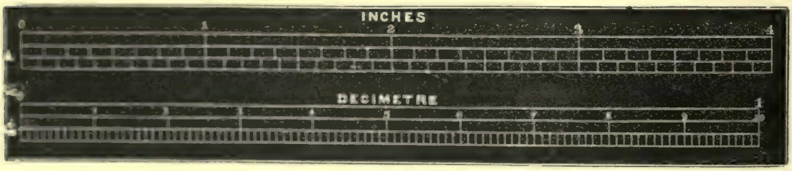
The French unit of length, called the *mètre* (from μετρέω, I measure), has been taken as being the ten-millionth part of the quadrant of a

meridian passing through Paris; that is to say, the ten-millionth part of the distance between the equator and the pole, measured through Paris. It is equal to 39·3707898 inches. The mètre is divided into one thousand *millimètres,* one hundred *centimètres,* and ten *décimètres;* while a *décamètre* is ten mètres, a *hectomètre* one hundred mètres, a *kilomètre* one thousand mètres, and a *myriomètre,* ten thousand mètres. The following table gives the value of these measurements in English inches and yards :—

	In English Inches.	In English yards.
Millimètre	0·03937	0·0010936
Centimètre	0·39371	0·0109363
Décimètre	3·93078	0·1093633
Metre	39·37079	1·0936331
Décamètre	393·70790	10·9363310
Hectomètre	3937·07900	109·3633100
Kilomètre	39370·79000	1093·6331000
Myriomètre	393707·90000	10936·3310000

One English yard is equal to 0·91438 mètre; while one mile is equal to 1·60931 kilomètre.

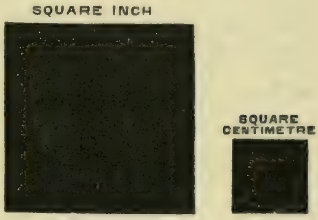
In the annexed woodcut a décimètre, with its divisions into centimètres and millimètres, is shown, and compared with four inches divided into eighths and tenths.



Unit of Surface.—For the unit of surface, the square inch, foot, and yard adopted in this country are replaced in the metric system by the square millimètre, centimètre, décimètre, and mètre.

1 square mètre	=	1·9160333	square yards.
1 square inch	=	6·4513669	square centimètres.
1 square foot	=	9·2899683	square décimètres.
1 square yard	=	0·83609715	square mètre.

In the annexed woodcut a square inch and a square centimètre are shown, in order to give an idea of measures of surface which will often be referred to in the following pages.



Unit of Capacity.—The cubic inch, foot, and yard furnish measures of capacity; but irregular measures, such as the pint and gallon, are also used in this country. The gallon contains ten pounds avoirdupois weight of distilled water at 62° F.; the pint is one-eighth part of a gallon. The French unit of capacity is the *cubic décimètre* or *litre* (*λίτρα*, the name of a Greek standard of quantity), equal to 1·7607 English pints, or 0·2200 English gallon; and we have cubic inches, décimètres, centimètres, and millimètres.

1 litre	=	61·027052 cubic inches.
1 cubic foot	=	28·315311 litres.
1 cubic inch	=	16·386175 cubic centimètres.
1 gallon	=	4·543457 litres.

Unit of Mass or Weight.—The English unit of weight—the pound—is derived from the standard gallon, which contains 277·274 cubic inches; the weight of one-tenth of this is the pound avoirdupois, which is divided into 7,000 grains. The French measures of weight are derived at once from the measures of capacity, by taking the weight of cubic millimètres, centimètres, décimètres, or mètres of water at its maximum density, that is at 4° C. A cubic mètre of water is a tonne, a cubic décimètre a kilogramme, a cubic centimètre a gramme, and a cubic millimètre a milligramme.

	In English grains.	In lb. Avoirdupois. 1 lb. = 700 grammes.
Milligramme ($\frac{1}{1000}$th part of a gramme)	0·015432	0·0000022
Centigramme ($\frac{1}{100}$th „ „)	0·154323	0·0000220
Décigramme ($\frac{1}{10}$th „ „)	1·543235	0·0002205
GRAMME	15·432349	0·0022046
Décagramme (10 grammes) . . .	154·323488	0·0220462
Hectogramme (100 „) . . .	1543·234880	0·2204621
Kilogramme (1000 „) . . .	15432·348800	2·2046213
Myriogramme (10000 „) . . .	154323·488000	22·0462126

Besides these units, there are others on which a few words may be said, as the units before referred to are implicated. The *Unit of Time or Duration* is the same for all civilised countries. The twenty-fourth part of a mean solar day is called an hour, and this contains sixty minutes, each of which is divided into sixty seconds. The *second* is universally used as the unit of duration.

Having now units of space and time, we are in a position to fix upon a *Unit of Velocity.*—The units of velocity adopted by different scientific writers vary somewhat; the most usual, perhaps, in regard to sound, falling bodies, projectiles, &c., is the velocity of feet or mètres per second. In the case of light and electricity, miles or kilomètres per second are employed.

We have next the *Unit of Mechanical Work.*—In this country the unit of mechanical work is usually the *foot-pound,* viz. the force necessary to raise one pound weight one foot above the earth in opposition to the force of gravity. A *horse-power* is equal to 33,000 lb. raised to a height of one foot in one minute of time. In France the *kilogrammètre* is the unit of work, and is the force necessary to raise one kilogramme to a height of one mètre against the force of gravity. One kilogrammètre = 7·233 foot-pounds. The *cheval vapeur* is nearly equal to the English horse-power, and is equivalent to 32,500 lb. raised to a height of one foot in one minute of time. The force competent to produce a velocity of one mètre in one second, in a mass of one gramme, is sometimes adopted as a unit of force.

Unit of Heat.—These units vary: the French unit of heat, called a *caloric*, is the amount of heat necessary to raise one kilogramme (2·2046215 lb.) of water one degree Centigrade in temperature; strictly from 0° C. to 1° C. In this country we sometimes take one pound of water and 1° Fahrenheit as the units; sometimes one pound of water and 1° C.

Thermometric degrees.—The value of different thermometric

degrees is discussed in the *Forces of Nature* (*vide* Heat, Book IV., Chapter i.). The following facts may be found useful:—

1° Fahrenheit	=	0·55° C.	=	0·44° R.
1° Centigrade	=	0·80° R.	=	1·80° F.
1° Réaumur	=	1·25° C	=	2·25° F.

Centigrade degrees	÷	5	×	9	+	32	=	Fahrenheit degrees.
Réaumur ,,	÷	4	×	9	+	32	=	,, ,,
Fahrenheit ,,	−	32	÷	9	×	5	=	Centigrade ,,
,, ,,	−	32	÷	9	×	4	=	Réaumur ,,
Centigrade ,,	÷	5	×	4			=	,,
Réaumur ,,	÷	4	×	5			=	Centigrade

THE APPLICATIONS OF PHYSICAL FORCES.

THE

APPLICATIONS OF PHYSICAL FORCES.

INTRODUCTION.

I.

IN a former work—the *Forces of Nature*—an attempt was made to give a popular account, easy of comprehension to all, of the outlines of those Natural Phenomena known to the scientific world as Gravity, Heat, Light, Magnetism and Electricity. In describing these various phenomena I endeavoured especially to point out some of their most simple and general laws, without having recourse to figures or formulæ. The principal object of the *Forces of Nature* indeed was an exposition of the principles of pure science, without reference to the uses which are or can be made of them. The object of the present volume is to complete this account of the physical side of Science by describing the most remarkable of its applications, not only in the Arts and Industries, but in the further investigation of Science itself.

Who now-a-days will deny the influences and importance of the Applications of Science? Who can deny the ever-increasing part which the practical deductions from scientific theory play in the general progressive movement of modern societies? Everywhere now we find examples of them, under the most diverse forms, in private and public life, in our dwelling-houses, and in our national edifices. They follow us in the actions of every-day life, our work, our pleasures; they are present with us at the domestic hearth, and in our travels; they are associated with our joys and our

sorrows. In peace and war they hold the first place: here to destroy a hostile force or to increase the elements of defence or resistance: there, always fertile and helpful to man, to multiply and make perfect the implements of work and industry. In every case they enable us to live, and make the conditions of living more easy.

If we wish to form a striking idea of the importance which scientific applications have acquired during the last two centuries, we have only to imagine some of them as not existing, so that we should have to resort for the services they render us, to the primitive ways of our fathers in ordinary industrial operations before science was brought into play. Let us see what perturbations would be introduced into society and into the lives of each of us by this imaginary abolition of science, if such were possible. We have now returned, then, not, let us say, to the time which preceded Papin and the invention of the steam-engine, but only to that when the new machine, in an embryo state, was hidden away in the mines of Cornwall, waiting to be transformed by the genius of Watt. Thousands of workshops, three-fourths of their activity having been set in motion by the steam-engine, are closed, or at least they have to go back to their original implements, those only known to them when they were, strictly speaking, simple *manufactories*: the hand of the workman alone henceforward must make the thousand things indispensable to our wants, which in the present day the steam-engine produces with such astonishing perfection and wonderful and therefore economical rapidity.

In what an enormous proportion the industrial production of the world would suddenly be reduced! Take, for example, England. At the present time the steam-engines on English soil and in English manufactories have a mechanical power representing no less than seventy-six millions of workmen, that is at least ten times the muscular power of all the adult workmen who are the auxiliaries to the machines. Where would men be found to carry on the enormous work now done?

Let us extend this idea to all the manufacturing nations of the globe, and then only shall we be able to judge of the *famine* of manufactured goods, stuffs, clothes, tools, machines, and useful products of all sorts, which would be brought about by such a suppression as the one we have imagined.

We must not forget also that machines which owe their motion to the elastic force of steam, have not limited their services, in the century in which they have been invented and improved, to direct production. They have rendered possible the more perfect manufacture of all other machines and of a multitude of appliances and tools, without which a hundred industries would in the present day be either abolished or reduced to the rudest of primitive methods of production.

In industry, then, this is what would happen by the suppression of the steam-engine. But what confusion this suppression would also bring about in our commercial and other relations? At the present time steam is the great carrier. What would happen if suddenly the 300,000 or 400,000 kilometres of existing railways were to cease working, and if steamships no longer continued their customary journeys on the rivers, canals, and seas?

I have purposely chosen as an example of the applications of science one which has transformed, in the deepest and most universal way, the conditions of labour and of international and national relations. But, by making a similar supposition with regard to each of the principal modern inventions, if the consequences were not operative on such a large scale, still it would not follow that they would be less obvious to each of us. We have at the present time a thousand habits, a thousand wants, which would be satisfied with difficulty, were the inventions to be abolished which have caused them little by little to exist. This each of us can easily verify for himself by considering all those things which surround him which are, directly or indirectly, connected with an invention or an improvement which had science for its origin. The account of the principal applications described in this work, although restricted to one science, that of Physics, will clearly prove the truth of the statement we have just dwelt upon.

II.

Let us follow the natural order of the subject, and commence with the scientific applications of the fact that bodies have weight. These are, with few exceptions, at once the most anciently known and the most generally employed.

If the weight of bodies is frequently, from the point of view of work, an obstacle to be overcome, it is also a useful auxiliary which machines of all kinds continually and necessarily use: here we are in the domain of Applied Mechanics rather than that of Physics. Of these applications, we shall only refer to a few of the most striking. In some it is the energy of the bodies which fall under the action of gravity or weight, rather than their dead weight itself, which produces the desired effect. In other cases, it is the play of relatively minute actions which, thanks to the properties of fluids, gives rise to effects which may be called prodigious: the hydraulic press, for instance, Pascal's idea, which was only realized a century after his time, shows us the muscular power of a single arm increased a hundredfold by the powerful machine flattening and crushing the most resisting materials, and lifting enormous weights to considerable heights. Moved by steam, the hydraulic press has raised gigantic iron-plated tubes, weighing not less than two millions of kilogrammes, to a height of thirty or forty metres. These now form the tubes of the famous bridge over the strait separating the Isle of Anglesea from the county of Carnarvon.

Another new invention has permitted the undertaking and bringing to a successful termination that grand work the Mont Cenis Tunnel, under the masses of the Col de Fréjus, a work which is being repeated under the Saint-Gothard. We refer to the use of air compressed by a fall of water into reservoirs, by which it is forced into the tunnel. Thus transformed, the force of gravity puts into motion the boring tools which pierce the rock; then, when gunpowder has completed the work, the air, escaping from compression, replaces the impure and smoky atmosphere of the gallery. Thus where steam has failed, the mechanical compression of air obtained by a waterfall, that is, by weight, triumphs.

Compressed air also renders possible the rapid construction and foundation of piers of bridges thrown across arms of the sea or wide rivers; and, on some subterranean railways, sends the train from one end to the other, like a pellet out of a pop-gun. In Paris, London, and New York it transmits despatches between outlying telegraphic stations and the central one. A vacuum made by a powerful pneumatic machine on one end of a piston moving in a tube, brings into play the pressure of the air at the other end,

which supplies a force sufficiently great to force a heavy weight supported on wheels along the tube. This process, which is the opposite of the application of compressed air, is also adapted to the service of telegraphic and postal despatches.

One physical principle, which is associated with weight, the discovery of which is of great antiquity—it takes the name of the great man who discovered it, Archimedes—was at the end of the last century applied to produce the ascent of balloons in the air. The art of the aëronaut, greatly improved since Montgolfier's time, has become popular; and each year balloons traverse the aërial regions, in which curious phenomena have been discovered by their means; and in the hands of serious observers, they will end by unveiling many of the mysteries of the atmosphere.

Meteorology, as yet so backward, cannot fail to utilize its aid. Moreover, during the war between France and Germany, balloons were sent as messengers from the heart of Paris to every part of France, carrying in their frail cars to the provinces news of the besieged but confident population. Perhaps the day will come when the problem of the direction of aërial machines in their present form, or more probably in a new one, will be partially solved; when they will be able to tack about or cut through the air, as sailing or steam ships cut through the waves of the sea: then, instead of curious or exclusively scientific experiments such as are now made, real aërial journeys may be taken, and regular expeditions susceptible of useful applications.

III.

From the applications of the phenomena and laws of weight, we shall pass on to those which result from the phenomena and laws of sonorous vibrations.

Here we shall find ourselves almost exclusively in the domain of art, with that which moves and charms us with its vivacity, and at the same time with its profundity. Music, indeed, is not only an art, it is a science. Nevertheless it is in relation to neither of these that it borrows aid from applied physics. That wonderful natural instrument, the human voice, being left out of the question,

it is by the help of artificial instruments that music expresses the thought of the composer, that it gives shape to his melodies, and to the harmonies introduced into them to render them more expressive and penetrating. From the ancient lyre and harp to the modern violin, to the masterpiece of sonorousness and sweetness of Stradivarius to the powerful organ, so scientifically built by contemporary makers, what a numberless variety of musical instruments have by turns lent the help of their tones to musicians of all times and of all countries! It is true, that it has been by the long and patient researches of the makers, and by the results of experience rather than by the indications of theory, that most of these instruments have by degrees acquired their actual perfection. It must be also added that all the conditions of this perfection are far from being scientifically explained. It is not less curious to know how the laws of the sonorous vibrations, which govern the series of notes of the musical scale, are followed and applied in the instruments of the different types, whatever may be the peculiar mechanism of each of them. How many persons play the violin, piano or wind instruments without having inquired into the action of the different parts of the instrument which is so familiar to them; how few know by what mechanism the organist produces that wonderful and powerful collection of sounds which bring before us all the tones with all their various qualities, imitating so exactly all the instruments of an orchestra and even the human voice!

Here we have an interest, due to curiosity, which will justify the chapters I shall devote to most of the known instruments, by considering them as so many applications of the phenomena and laws of acoustics. This is a novel subject and treated with unusual length in a work devoted to physics; yet it is but glanced at, as it would require a volume to give the subject the space which it allows and which it merits.

IV.

With Light and the applications with which the study of its phenomena and laws have enriched science, we enter two new worlds: new, doubtless to those among us who have not studied

either physical astronomy or physiology, who have never yet looked through a telescope or microscope; but certainly new worlds to all those who lived two centuries ago. Before Galileo's time what unknown wonders in the depths of the sky, in the world of the infinitely great! What astonishing revelations in the world of the infinitely little, since Swammerdam! New sciences have sprung up which would not have been possible without the help of these powerful means of investigation placed by optics at the disposal of observers. Thanks to the microscope, the structure of the animal and vegetable tissues, the most capable of disclosing the mechanism of life, is known in its most minute details. By means of the telescope the eye penetrates into infinite space, and there discovers millions of stars, the existence of which the eye could scarcely suspect—at such enormous distances, that it takes centuries and thousands of centuries for their light to reach us, although the light waves travel with prodigious velocity through the ether.

Nevertheless there is nothing more simple than the manufacture of these optical instruments, nothing more easy than to understand their principles and to explain their effects, and, lastly, nothing easier, with patience and study, than to acquire the practical knowledge necessary to their fruitful uses.

Other instruments, based on similar principles, such as heliostats, sextants, goniometers, then spectroscopes and apparatus for lighthouses, are employed for scientific researches of different kinds and render precious service in astronomy, mineralogy, and travels; on all accounts they deserve to be described and studied. The siderostat, an invention due to Hooke, Laussedat and Foucault, although it has not yet come into general use, must be referred to for the great help it is destined to render in the researches of physical astronomy, for instance, in the study of solar phenomena.

But one of the most interesting applications of the properties of light—an invention still recent and already brought to a rare degree of perfection—is that which allows us to reproduce instantaneously, and with wonderful fidelity, all objects illuminated by a sufficiently intense light source. In the present day photography is a popular art, popular in its processes and results, but none the less interesting in its principles and method, nor

less fruitful in its influence on the sciences and arts. By its principle, it has formed a new branch of science, photo-chemistry: as to the services it unceasingly renders to the arts and to the natural sciences, it is scarcely necessary to enumerate them. It is true that for a moment this means of reproduction of natural objects was injured by overrating the part to be taken by photography, and by supposing it would be able to supplant the artist: as if a mechanical process were capable of translating the sentiment of the painter, that is to say, the poet in presence of nature, sentiment being the true source of inspiration, without which there can be no masterpiece. The part filled by photography is both more modest and more useful: it popularizes the *chefs-d'œuvre* of painting, statuary, architecture, and engraving; it reproduces the smallest details of natural views, of the objects studied by the geographer, ethnologist, and naturalist; and enables the poorest to preserve the likenesses of those most dear to them, and in this sense it has and always will have a moralizing influence.

So much for the results. But if it is looked at from a scientific point of view, is not this automatic reproduction of natural objects marvellous—this painting with no other agent but that of light? Moreover, each step taken in this art reveals surprise after surprise: after photography comes heliography, which, if a few practical difficulties can be conquered, will soon enable photogenic images to be multiplied, just as typography multiplies books and ordinary engravings.

V.

I mentioned at the beginning of this introduction the most considerable application of the phenomena and laws of heat, that which is based on the transformation of heat into mechanical power. No physical application can rival the steam-engine in the immensity of its results. Socially speaking, it is by producing power that the worth of man, whether we deal with the individual or the nation, is estimated.

Now, steam has increased the sum of the forces of which man can dispose for the satisfaction of his wants: in an enormous proportion it is just as if it had increased his capacity for work

in like proportion. But production is not everything; and to produce a great deal, it is necessary to move and distribute the produced riches with a rapidity and regularity increasing with the increase of production: steam, in the form of railways and steam-vessels, has solved the problem. Lastly, it was necessary still to increase the rate of communication which the post and railways had already so much accelerated: commerce required this increase of speed; politics demanded it. The locomotive and steam vessels having in this respect done their utmost, another physical agent has been brought into play. I do not know which is most astonishing, the invention of the electric telegraph and the rapidity with which this invention has been realized and propagated over the entire globe, or the indifference with which we now look upon that which would have appeared the most extraordinary of miracles in past centuries.

Here we have written a few lines on a piece of paper not larger than the hand; with the signature attached, the whole is given to a clerk in the telegraph office in London, who places the paper on the plate of his instrument. In less than two minutes afterwards the telegram has been printed in Edinburgh. This astonishing rapidity is only half the wonder: between Paris and Marseilles, for instance, the writing, with its autographic physiognomy and the signature, with all its peculiarities, is also reproduced in fac-simile, with irreproachable exactness, on a square of paper the same size, placed in the same way on an instrument situated 864 kilometres distant from the first. Add to that the time necessary to transmit the message to its destination, and the reply autograph, like the telegram itself, returns from Marseilles to Paris with equal rapidity. A motion communicated to a heavy pendulum, with a pencil which swings across the paper and passes over every part, this is all that can be seen of the wonderful operation which has taken place before our eyes, of which, unless by the initiated, nothing can be understood.

Does not this indeed appear quite incomprehensible? It is true nevertheless; and the doer of this scientific miracle, which has nothing supernatural in it, is electricity. It is the current generated in a pile, circulating with the rapidity of thought or lightning in the wires stretched between the two stations, and magnetizing

in its passage the soft iron inclosed in the bobbins or electro-magnets, which, after a series of movements which we can only refer to now, acts each time the current passes over the tracing pencils of the instruments. But chemical reaction gives birth to the invisible current; and a chemical reaction is produced at the end, and a series of coloured points traces on the paper the very image of the characters written at the point of departure. A drawing, plan, or any figure, or shorthand signs can, of course, be also thus reproduced.

A thousand other curious inventions—that which I have just quoted is doubtless among the most striking—have been realized from the same principle: that of the action of electricity at a distance. This force, the real nature of which is still unknown, and of which three centuries ago the existence was scarcely dreamt of, which before that time was only manifested under the form of thunder—this force has become, thanks to science, thanks to the experimental investigations, and also—and this we must emphasize—thanks to the indications of theory, the docile agent of man. It transmits human thought to a distance, whether along aërial wires or through cables which are immersed in the depths of the ocean; at a distance it sets fire to mines and torpedoes; it is a light-source which rivals the sun; it transmits and regulates the movement of clocks; it melts metals; it covers objects with an imperceptible layer of a precious metal, gold, silver, or platinum; and, lastly, it reproduces the works of the sculptor or the modeller.

VI.

To bring together in a single work all these many different applications, to describe the instruments, machines, and apparatus of all kinds, by the help of which inventors have succeeded in realizing them; to make them easily understood, in principle if not in detail, such is the aim proposed in this work. The various chapters which compose it do not pretend to replace technical manuals, by means of which each application is studied for practical purposes. Besides, the idea of the book is far different, as I have before stated. The present volume is the complement of the one in which the phenomena and their laws have been studied. The

two works have the same plan; the division of matter is the same, because it was necessary above all that the reader should connect in each subject the principle with its consequences, so that thus practice and theory may be mutually understood.

In conclusion I must add, in the hope of deserving at least the indulgence of the public for the literary form of this work, that I have been more anxious to instruct than to amuse. The subject does not border on fiction; but I am convinced it will be none the less interesting for all that. The important point was to treat the subject with all possible clearness; and here, as in some other works which have been received with favour, I have especially endeavoured to be clear.

BOOK I.

APPLICATIONS OF THE PHENOMENA AND LAWS OF WEIGHT.

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APPLICATIONS OF THE PHENOMENA AND LAWS OF WEIGHT.

THERE is no part of human activity dealing with matter in which the weight of bodies, whether they are solid, liquid, or gaseous, does not enter, and in which therefore the effects of weight have not to be taken into account and to be calculated. This is as necessary for equilibrium as for motion. Thus notably such constructions as monuments, public and private buildings, bridges, aqueducts, and those movable bodies used in land, river, and sea transport, together with apparatus, engines, and tools of all kinds, may with good right be considered from the point of view of equilibrium or stability and of motion as so many physical applications, and especially as applications of the phenomena and laws of weight.

But one can easily understand that we in no way intend to carry out so large a survey. The meaning we shall give to physical applications is much more restricted: we shall refer only to those of which the principle is borrowed from physics, to the forces and to the laws which these forces manifest, leaving on one side the numerous applications which depend exclusively upon Mechanics. This remark applies to all branches of physics, but in this First Book devoted to Weight we shall only pass under review and describe those applications, or machines based upon some of the laws of gravity, such, for instance, as the constancy of the direction of this force on the surface of the earth; the energy developed in a body which falls from a height; the isochronous oscillations of pendulums; atmospheric pressure, and the like. Further, we shall deal chiefly with those

which have the greatest value, and of which the use is most obvious; or, again, with those which are more specially interesting from a purely scientific point of view. Some of these applications have come down to us from a high antiquity, others are of recent date, but we shall endeavour to give the most recent developments.

We shall find in many cases that the discovery of a physical law has been the consequence of an entirely empirical inquiry, having for its object the perfection of a certain branch of industry; and, again, in other cases that a discovery of great commercial importance has been brought about by an experimental or mathematical demonstration of a truth of the most abstract order. These are considerations on which we most strongly insist: because, in our opinion, they have a real philosophical importance. They seem to us, in fact, to be well qualified to warn our readers against two opposite tendencies, both unfortunate. On the one hand we find persons conscious of their practical skill disdaining scientific theory; while on the other, some men of science who consider themselves to be great philosophers look down upon knowledge acquired in the operations of industry, though the knowledge is often of a very real kind, and far removed from the so-called "rule of thumb."

CHAPTER I.

DIRECTION OF GRAVITY—FALL OF BODIES—OSCILLATIONS OF THE PENDULUM.

§ I.—Plumb-line and Levels.

IN the arts, and especially in the art of building, it is frequently necessary to establish vertical or horizontal lines or planes; or, if these lines or planes are already constructed, it becomes equally important to test their accuracy. This is done by means of instruments called plumb-lines or levels, both based on the fact that a thread or string stretched by a heavy body lies, when at rest, in the exact vertical of the place where the observation is made.

Most people have seen the plumb-line used by masons, which consists of a thread, with a cylindrical metal weight attached, and a square plate, also of metal, the side of which is equal to the diameter of the cylinder. The plate slides, by means of a central hole, along the thread and is placed against the wall, the verticality of which is to be observed. When not in motion, the cylinder should lie along the surface of the wall, without resting against it and without leaving between it and the wall any perceptible interval.

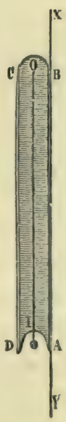

Fig. 1.

A flat rule or straight-edge (Fig. 1), having truly parallel edges (A B, C D), with a straight line (O I) drawn down the centre, called a test-line, is also used for the same purpose. One of the sides (A B) is placed against the line or plane to be tested, and

it is necessary that the thread fixed at O and stretched by a weight should coincide when at rest with the test-line of the rule. In order that the test be complete, the straight-edge ought to be reversed and the same experiment made with the side C D.

FIG. 2.—Masons', or perpendicular levels.

The levels shown in Fig. 2 are used to prove that a plane or a line is horizontal. The appearance of the instruments is sufficient to indicate the way in which they are employed, and we need not dwell longer on this simple application of the first law of gravity, which teaches us that its direction is constant in one place.

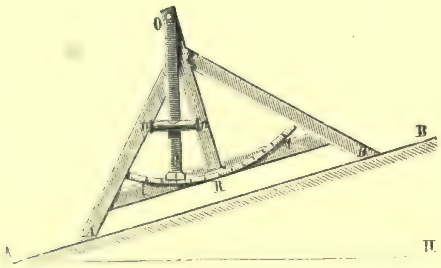

FIG. 3 – Delambre's perpendicular level for geodetic observations.

In geodesy, the perpendicular level (the name given to the instruments represented in Figs. 2 and 3), made with the greatest accuracy, is used to measure the angle of inclination of a straight line to the horizon. The plumb-line is replaced by a heavy rod suspended at O, the lower extremity of which is furnished with a vernier. A graduated limb gives in degrees the value of the angle (P O R) formed by the level and the test-line. The inclination of a line (A B) to the horizon (A H) can thus be found; P O R is, in fact, equal to the angle B A H, as the two sides of these two angles are perpendicular to each other.

Delambre, in his measurements of the meridian, used a perpendicular level thus arranged, in order to determine the inclination to

the horizon of the rods which he used to measure his base lines, and a similar instrument called a *clinometer* is used by geologists to determine the angle of strike or dip of strata.

We shall refer further on to other levels used by artificers and engineers, called "spirit-levels" and "water-levels," in which bubbles are used, when we come to speak of the equilibrium of liquids.

§ II.—PILE-DRIVERS.

A heavy mass falling from a certain height moves, we know, with a velocity increasing as the square of the distance through which it falls. The work or mechanical effect thus developed by the action of gravity, and which is measured by multiplying the mass by the square of the velocity or by the height, is utilized for driving stakes or piles to form the foundations of piers of bridges and other great hydraulic works. The name of pile-drivers is given to machines used to lift, guide, and let fall masses of cast-iron called monkeys on the head of piles. Hand pile-drivers and mechanical pile-drivers are represented in Plate I. They differ from each other inasmuch as in the first the working of the machine, both in lifting the monkey and in letting it fall down and slide between the two side-beams, is done with ropes drawn by a gang of workmen.

In the second, by the aid of a windlass, one or two workmen are sufficient to raise the monkey to the desired height. On reaching this point, the weight, which during its elevation was held, by means of a ring, by two nippers, is freed, and falls on the head of the pile.

The mechanism which sets free the monkey will be easily understood by glancing at Fig. 4, which represents the detent.

Two strong nippers fixed in the ring, which terminates the upper part of the monkey, are kept closed by a spring during its rise; but when it reaches the end of its course, the upper arms of the nippers pass into a narrow opening in the form of a cone; they are gradually brought together, opening the two lower jaws which free themselves from the ring, and the monkey descends.

Most frequently the work is commenced with the manual pile-drivers, which have the advantages of simplicity and rapidity in working, although they only raise the monkey to a height of about 1

metre or $1^m\ 20$. When the piles, already driven to a certain depth, only give way slowly under the strokes of this machine, the mechanical pile-drivers are employed to finish the work. With these the weight can be lifted to a height varying from $2^m\ 5$ to 5 or 6 metres. The useful effect, which depends on the height of the fall, is therefore much more considerable. The weight of the monkey varies from 300 to 600 kilogrammes, and the number of men necessary to the working of the manual pile-drivers reaches sometimes as many as forty. Recently steam has been applied to these machines, as seen in Plate I.; a portable steam-engine giving motion to the machine. It does not appear that steam has hitherto been used *directly* for pile-driving, yet the difficulties of its application for that purpose do not appear to be insurmountable. A fixed boiler at the base of the machine, and a steam-hammer capable of being fixed at any height and connected with the boiler by flexible tubing, if necessary, would appear to be all that is required for the application of steam for this purpose. An American invention has recently increased the force of the fall by causing the monkey at the moment the detent is opened to explode a small charge of gunpowder.

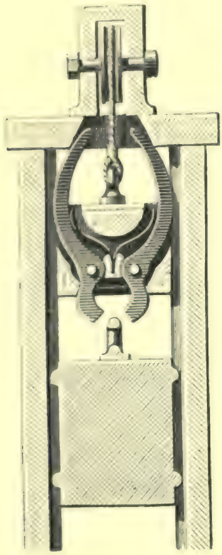

FIG. 4.—Details of mechanism in the detent.

The steam-hammer, which is a kind of monkey used in forging metals, is, like the pile-driver, an application of the force of gravity. We only speak of them here in passing, as we intend to refer again to them in the chapters devoted to steam. Here, indeed, we must keep well before our minds one important application of the force developed by a heavy mass in its fall, under the sole action of weight.

We must remark, in concluding, that all this force is not utilized in producing the desired effect, which is the driving of the piles: a part is transformed into heat, that is to say, into a molecular movement common to both masses which are thus suddenly brought into contact—the monkey on the one side, and on the other the head of

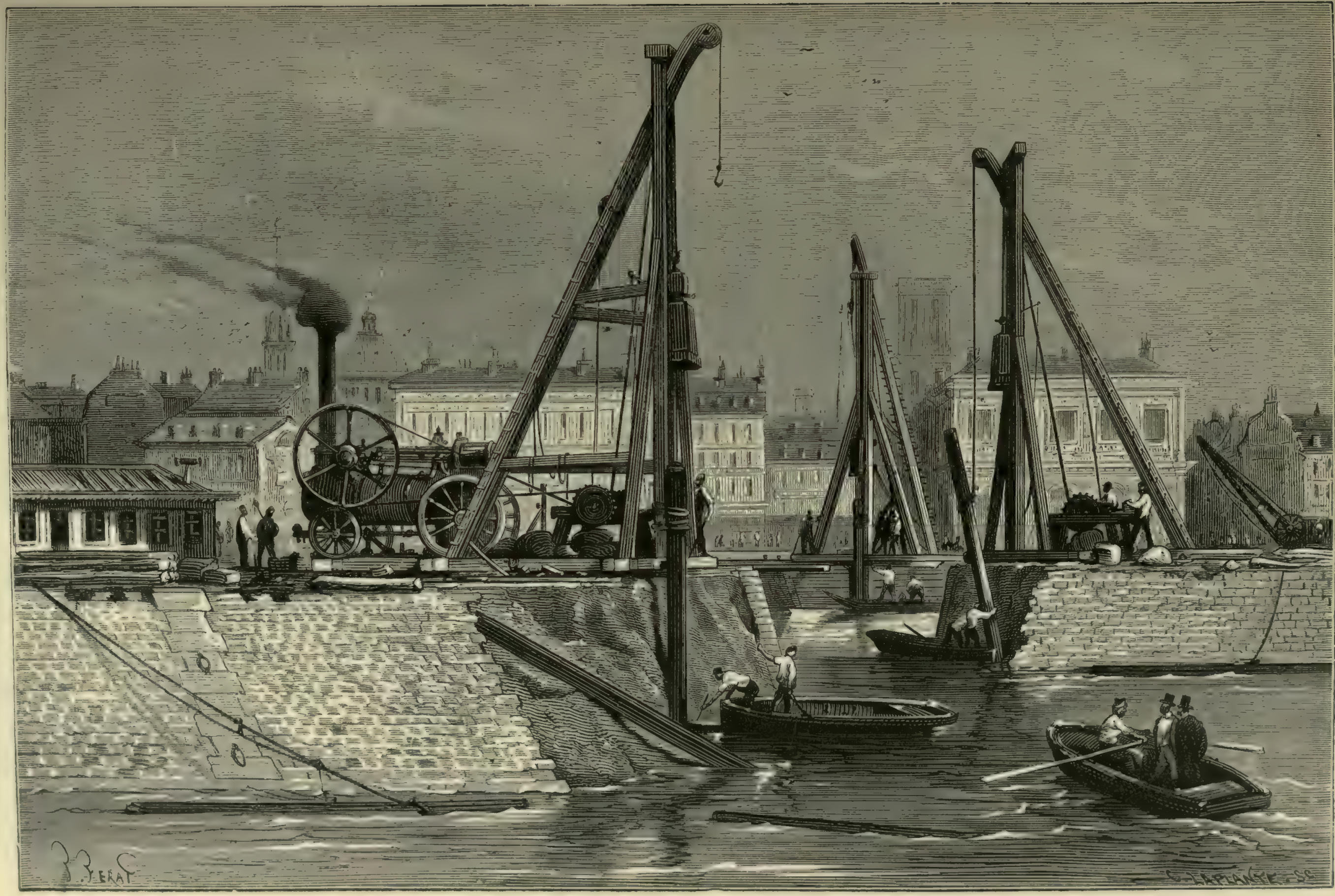

PLATE I.—STEAM AND HAND PILE-DRIVERS.

the pile and the iron ring with which the head is fitted to resist the lateral strain which, without it, would split the piece of wood into fragments.

§ III.—Clock Pendulums.

Galileo, after discovering that the oscillations of the same pendulum took place sensibly in equal times, when their amplitude was very small, thought to utilize this valuable property in measuring the exact number of beats of the pulse. The instrument called the *pulsilogium*, which is simply a pendulum, was, it is said, invented by him.

But it appears certain that Huygens was the first inventor of the application of the isochronism of the pendulum to clockmaking (1656). For nearly three centuries and a half clocks with cogged wheels had been used, but they were as yet very imperfect instruments, not having a constant regulator of their movement. Huygens solved the problem in the following manner :—It is known that in clocks the motive power is sometimes a weight, which, under the influence of gravity, unwinds the cord by which it is suspended, and thus continuously turns the axis of a cogged wheel; and sometimes it is a steel spring, which unbends gradually, and, since by a special mechanism its action is rendered almost regular, this spring also causes the cogged wheel to move in a continuous manner. In both cases this wheel transmits its movement to all the other parts of the clock.

In both cases, also, the difficulty was to establish a perfectly regular and uniform movement, notwithstanding all the causes of error and the variety of resistances presented by the action of so many parts. This was accomplished in different ways, by transforming the continuous movement given to the wheelwork by the motive power into an oscillatory or periodical one, by using a regulator. The most simple and at the same time the most exact regulator of clocks is the pendulum. Huygens's arrangement is shown in Fig. 5.

R is a cogged wheel with oblique teeth, to which a movement is communicated by the spring or weight of the clock. This motion it

afterwards transmits to the system of pinions and cogged wheels forming the clock mechanism. In the figure, for simplicity's sake, we have omitted the intermediate wheels. P P′ is the pendulum or regulator of the movement. Its oscillations are transmitted to E by means of the fork *f*, and from the arbor E D to the pallet A B C, which is called an anchor-pallet from its form. A B C then oscillates in the same manner as the pendulum itself. And as its two extremities A C are curved in such a manner as to allow them to fall between the teeth of the wheel R during the time that one of the teeth rests on the upper surface of one of the extremities of the pallet, the movement of the wheel is checked. At each oscillation of the pallet, a tooth of the wheel thus stopped frees itself and the movement

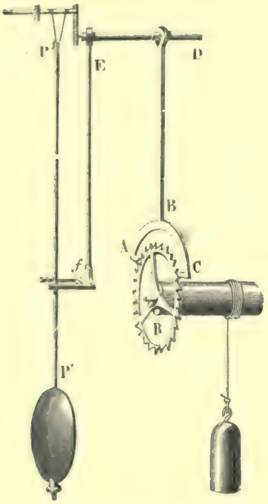

FIG. 5.—Mechanism of the regulating pendulum.

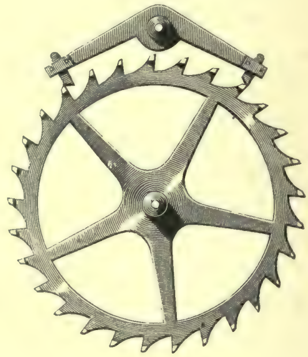

FIG. 6.—Anchor escapement.

continues, so that the movement, which would be continuous if it were due to the action of the weight alone, becomes periodic, the duration of each period being that of one oscillation of the pendulum.

As the beats are isochronous, the movement of the toothed wheel is also isochronous, and that of all the other wheels. But the arrangement of the portions A and C is such (Fig. 6) that each time the tooth of the wheel presses on one of them to free itself, it communicates its movement to the anchor, then to the pendulum, the arc of oscillation of the latter thus remains constant; and the oscillations are stopped only when the motor, either weight or spring, ceases to act.

The time of oscillation of the pendulum depends on its length, and this length is determined for each clock by the connection or train of wheels between the minute hand and the scape-wheel. It will thus be seen that the function of the pendulum is to regulate the movement of the wheelwork by changing this continuous movement into a series of oscillatory movements in equal times. But as it receives its momentum from this wheelwork, the force of which may vary from different causes, it follows that the arcs of these oscillations are liable to decrease: their duration is then shortened, even though the length of the pendulum is not altered, and the clock would go faster. Huygens sought for and found the means of solving this difficulty by an admirable discovery which, unfortunately, cannot be adopted on account of the difficulties which the application presents. We refer to the cycloidal pendulum, thus named because it is based on the principle of the geometric curve called a cycloid.

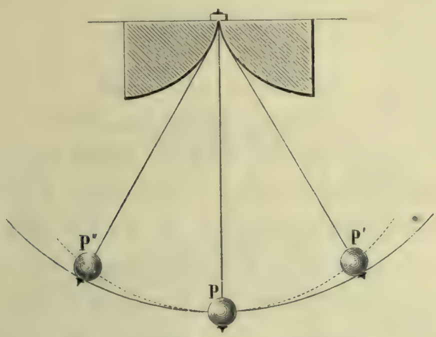

FIG. 7.—Huygens' cycloidal pendulum.

The rod of this pendulum is a flexible metallic plate, suspended between two solid cheeks taking the form of two cycloidal arcs tangent to the starting-point. In oscillating, the flexible rod bends and rests on each of these arcs by turns, and the length of the pendulum thus diminishes in a degree which depends on the extent of the oscillations. Huygens found that, if the diameter of the generating circle of the cycloidal arcs has a length equal to half that of the oscillation of the pendulum, the centre of the bob describes an arc (P'' P P') which is itself a cycloidal arc.

Now a heavy body which moves by gravity in an arc of this kind takes the same time to reach the end of its path at P, whatever may

be the height of the point of departure. In a word, the oscillations of the pendulum are always isochronous, and this isochronism is independent of the amplitude of oscillation. Another difficulty presents itself, inasmuch as the length of the pendulum varies with the temperature, increasing when the temperature increases, and lessening when the temperature lessens. We shall see further on, in the Book devoted to the applications of heat, how these difficulties have been surmounted. We may here conclude by emphasizing the extreme importance of Huygens' discovery consequent on Galileo's observations. From this period—a little more than two centuries ago—clock-making has become an art of such precision as to render most valuable service to all the physical sciences, and especially to astronomy.

§ IV.—The Movement of Rotation of the Earth and Apparent Deviation of the Pendulum.

We mentioned in the *Forces of Nature* some of the applications of the properties and laws of the pendulum to the physics of the globe. It remains for us here to say a few words about an experiment which, some years ago, took great hold on the public. We speak of the experimental proof of the rotation of the earth by the deviation of a pendulum, a proof thought out and realized by Foucault. The experiment of which we speak is based on a principle of mechanics, which, applied to the rotation of a spheroid like the earth, may be summed up in these three propositions :—

1. A pendulum placed at one of the poles of the earth, its point of suspension being in the axis of terrestrial rotation, will oscillate so that the plane of its successive oscillations would maintain a constant direction in space. Then an observer placed at that spot, finding himself drawn round by the rotation of the earth, without being conscious of his own movement, would believe he saw the pendulum oscillate in variable planes coinciding successively with all the meridians. After a sidereal day, that is, after twenty-three hours fifty-six minutes of mean time, the plane of oscillation of the pendulum would appear to him to have gone through a complete revolution, and in a direction opposite to that of the rotation of the earth.

2. At the equator, on the other hand, the rotation of the globe would not have any influence on the apparent direction of the plane of the oscillations, which would appear to be, and indeed would be always the same relatively to the horizon.

3. Lastly, theory establishes that in all other latitudes the ap-

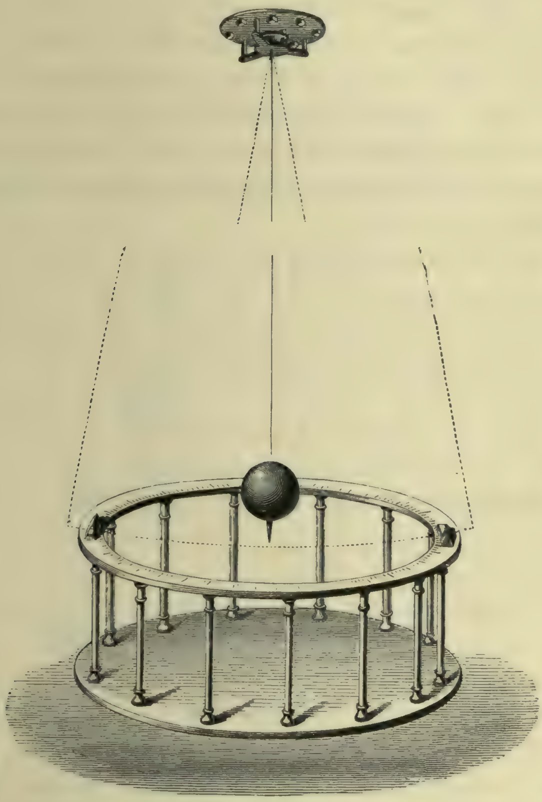

FIG. 8.—Foucault's pendulum experiment.

parent deviation of the plane of the oscillation of the pendulum would be made in the direction of the nearest pole, the deviation being slower according as the place where the experiment is made is nearer the equator. Calculation shows that at Paris (latitude 48° 50′) the pendulum would take about thirty-two hours to accomplish the entire round of the horizon, friction at the point of suspension and that due to the resistance of the air not being taken into account.

This result of theory was confirmed at Paris in 1851, under the dome of the Pantheon, by Léon Foucault. This distinguished physicist arranged his experiment, which attracted a number of curious people, in the following way:—At the highest point of the interior of the dome a steel wire about 64 metres in length was firmly fixed into a metal plate; this carried at its extreme end a very heavy brass ball. When removed from its vertical position and left to itself, this pendulum very slowly executed a series of oscillations in a plane which theory, as we have before stated, proves to be invariable in space. On the hypothesis of the earth being stationary the orientation first given to this plane would therefore have been kept. Now, the numerous spectators of this curious experiment were able to observe a deviation.

In one hour, the arc measuring this deviation was very nearly that indicated by theory, namely 11° 17′ 39″. Two little mounds of sand placed on a circular balustrade and at the extremities of the same diameter, were by degrees cut through in opposite directions by a metal point fixed below the ball of the pendulum, so that the apparent deviation of the plane of the oscillations, due to the rotation of our globe, and therefore this rotation itself, were rendered perceptible to the eyes of all.[1]

§ V.—Balances used in Commerce or in the Arts.

We have described the balance of precision in the first book of the *Forces of Nature;* it is the only one used for scientific determinations of weight requiring great accuracy. Other kinds of balances, more roughly constructed and intended for near approximations, are used in commerce and industry; we will hastily describe those most used, without entering into the details of their construction.

The Roman steelyard, called in France *Romaine,* is the one most anciently known: its French name is taken from the ancient Romans, by whom it was used. Its construction is very simple, and is based on the principle of mechanics that the weights of two heavy bodies

[1] Léon Foucault has demonstrated the rotation of the earth in another way, by a similar mechanical principle. The instrument to which we allude is the gyroscope. The reader will find the description of it in the most recent treatises on Mechanics.

acting at the extremities of two unequal arms of a lever are, when equilibrium is established, in the inverse ratio of the lengths of the arms of the lever.

In the Roman steelyard, the beam A B (Fig. 9) may be divided into two parts, the shorter of which (O A) forms one arm of the lever of constant length; at the extremity is suspended a hook or scale-pan intended to support the body to be weighed. On the longer part (O B), graduated properly into kilogrammes and fractions of a kilogramme, or in England to pounds, &c., moves a collar M, which supports a constant weight P: and it is this weight which, placed more forward or drawn back along the graduated rod, produces equilibrium with the heavy bodies placed in the pan Q, or hung to the hook. The

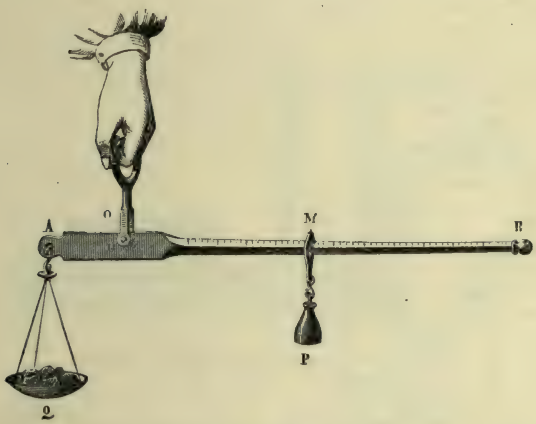

FIG. 9.—The Roman steelyard.

equilibrium is established when, after many oscillations, the beam retains a horizontal direction.

The steelyard is usually constructed so that the centre of gravity (O) of the whole instrument lies in the vertical which passes through the edge of the suspension knife and a little above it. Then, in the absence of the movable weight and of any weight placed in the pan, the beam remains in equilibrium and takes a horizontal position. The zero of the graduation is then at the point of suspension itself. The different divisions are ascertained by placing a known weight—one kilogramme or pound, for instance—in the pan and finding the point of the beam where the movable weight produces equilibrium: at

this point one kilogramme is marked. The space comprised between O and I, divided into decimal divisions and continued along the large arm of the beam, gives the graduation. This is a useful balance, as it does not require the use of a series of standard weights, and weighs large bodies with ease when an exact result is not necessary. It is not very delicate; its use is legally authorized in France only when it does not fail to indicate an excess of weight as much as the 500th part of its maximum load.

The weighing machine or the Quintenz balance (named after its inventor) is based on the same principle as the Roman steelyard—the body to be weighed and the weights acting at the extremity of the unequal arms of the lever. But there is this difference: the two arms are of invariable lengths, and it is at the extremity of the

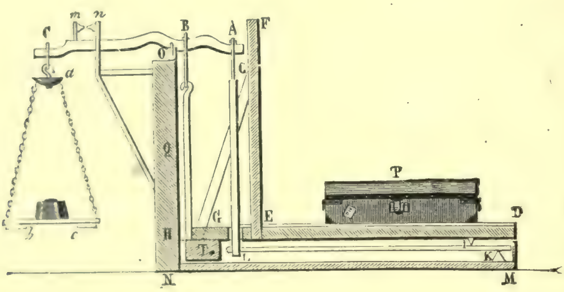

FIG. 10.—Weighing machine or Quintenz balance.

shorter arm that the body to be weighed is placed. The Quintenz balance then requires, like the ordinary balances, a series of weights; but these weights are less than those of the objects: for instance, if the relation of the levers O B and O A is that of 1 to 10, equilibrium will be obtained with heavy bodies by means of standard weights of one-tenth the weight.

The platform D E, on which the body to be weighed is placed, rests by a horizontal edge I on a piece K L forming a movable lever round K, and acting by the elbow L A on the arm O A of the beam. The distances I K and K L being made proportional to O B and O A, it follows from this arrangement that the platform D E, horizontal before the heavy body is placed on it, will remain horizontal when that body by its weight will cause it to give way, or, which

comes to the same thing, the movement from the point A will be to the movement from the point B in the same relation with the arms of the lever O A and O B. Hence it follows that the action of the weight of the body, passed to B and A, is the same as if it were all exerted at B; so that weights will suffice ten times less heavy than that of the body to be weighed to produce equilibrium. If the equilibrium, for example, is established in standard weights with 5·4 kil., the actual weight of the body is 54 kilogrammes. Balances of this kind, with additions and improvements, are much used in luggage booking offices, railways, and warehouses. When it is necessary to weigh carriages or loaded carts, they formerly used in France weighing-bridges, a sort of balance the principle of which is analogous to that of the balances of Quintenz, that is, it depends on a combination of levers of different lengths. In some foreign countries they still use weighing-bridges or the balances of Sanctorius (from the name of the distinguished Italian to whom the invention is attributed).

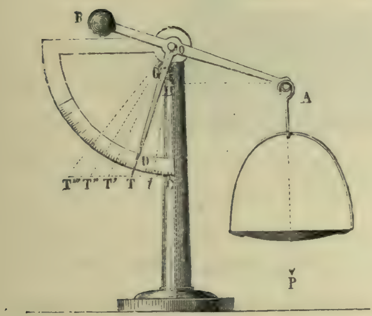

FIG. 11.—Peson.

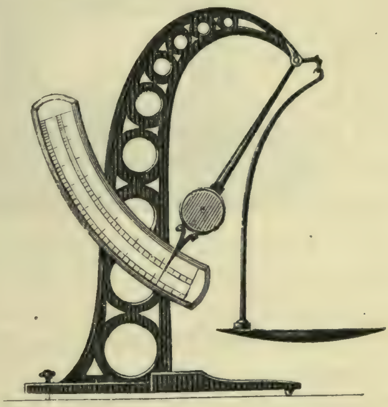

FIG. 12.—Letter-weight.

The peson is a form of steelyard, with immovable weight, used for the weighing of light materials, letters for instance (in this case it is called a letter-weight), or, in spinning factories for silk, wool, or cotton.

It is a lever, A B, made to turn round a point O. One of the arms, A, carries a pan intended to receive the materials to be weighed. At O is a needle fixed to the lever at a right angle. When there is no weight in the scale, A B remains horizontal, and the needle

then takes a vertical position; but when a body is placed in the pan, the action of this weight at the end of the arm of the lever O A moves the needle and causes it to traverse the divisions of an arc of a circle properly graduated. This instrument does not require the use of any weights. Its graduation is deduced from a very simple mechanical principle, namely, that the weights placed in the pan are proportional not to the angles that the needle makes with the vertical, but to the tangents of these angles, that is to say, to the distances C T, C T′ . . ., which the direction of the needle prolonged determines on the horizontal line drawn from the point C in the vertical line of O and tangent to the arc of the circle described from the point O as centre.

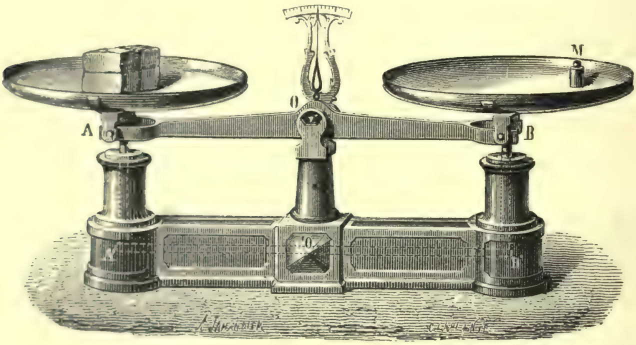

FIG. 13.—Roberval's balance.

We conclude this description of weighing instruments employed in commerce and the arts by a few words on Roberval's balance. The two pans of this balance rest, on the upper part of the beam, on two upturned knife-edges, and are fixed to two equal movable rods, connected at their lower extremities by rings to the two ends of a lever also movable on an axis at its centre. This arrangement, which changes none of the conditions of equilibrium, renders the use of this balance very convenient. The bodies to be weighed and the standard weights may be placed and taken away without interfering, as in the ordinary balance, with the cords or suspending strings of the pans. This form of balance is very extensively used in the present day.

CHAPTER II.

THE HYDRAULIC OR BRAMAH'S PRESS.—AREOMETERS OR HYDROMETERS.—ARTESIAN WELLS.

§ I.—The Hydraulic Press.

PASCAL demonstrated that all pressure exercised at one part of the surface of a liquid is transmitted with equal energy in every direction; hence he inferred that with comparatively little effort a considerable pressure might be produced, provided that a liquid, such as water, be used to transmit the pressure, and also that the piston by which the pressure is produced has a much smaller surface than that of the piston which is acted on by the pressure. In a word, he proved that pressure is transmitted and augmented in the proportion of the surfaces of the two pistons. Theoretically, this was the invention of the hydraulic press; but the difficulties of putting theory into practice did not at once allow of its construction. For a long time it was impossible to find any way of preventing the escape of water by the joints of the piston; an escape due to the very force with which the liquid when only slightly compressed was forced against the interior of the apparatus. A simple and efficient means of removing this inconvenience was adopted in 1796 by an English engineer, Bramah.

Fig. 14 represents the hydraulic press as used at the present day in the industrial arts for pressing certain substances. These substances, C, are placed between two plates, one fixed to the upper part of a solid structure, the other movable between uprights, and forced upwards by means of the head of the largest piston P. This latter descends into a cylinder full of water, M, which communicates by a

tube with a force-pump. The piston P of this pump receives the pressure to be transmitted, and acts like the smaller piston of the theoretical machine.

Let us now see, by the help of the figure, how these various parts are arranged and worked.

A B is the force-pump worked by a lever; the piston P presses the water of the reservoir *m* into the cylinder M. The pressure exerted by the liquid is transmitted to the piston P, and afterwards to the substances placed upon the plate C.

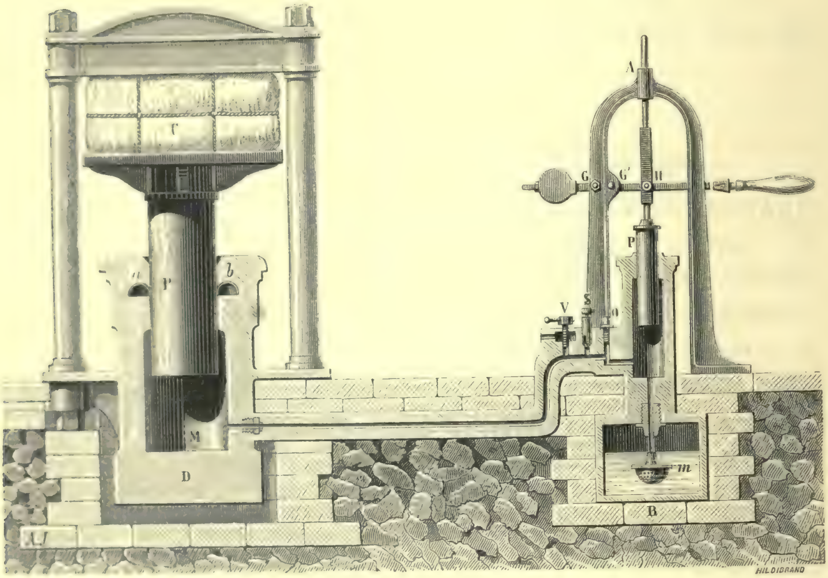

FIG. 14.—Section of a Hydraulic Pump.

To prevent the escape of water through the cracks of the joints of the piston P and from the cylinders, Bramah conceived the idea of reserving in the walls of the cylinder an annular space, *a b*, and of filling this space with a piece of leather cut first into the form of a flat ring and then bent over—that is to say, it took the form of an U reversed, as seen in Fig. 14. The water which penetrates below this ring in the annular space exerts its pressure on the lower surface of the leather; and the greater the pressure, the more forcibly is the ring applied both against the upper surface of the

cavity and against the piston itself, and the closer therefore is the joint.

The pressure, slight at the commencement of the operation when the substances to be pressed are still not firm, continues to increase until the degree of pressure wished for has been obtained. This result is brought about without the necessity of modifying the force used: the arm of the pump-lever is simply shortened. The pressure primarily depends on the relation of the surfaces of the pistons and on the length of the lever-arm used in the working. Thus the surface of the piston P is fifty times that of the piston *p*, and the distance from the point H, where the force is exerted, to the point G, on which the lever turns, is ten times larger than GH, the total transmitted pressure is 50×10 or 500 times that of the pressure applied. If this equals 100 kilogrammes, the pressure exerted will be 500×100, or 50,000 kilogrammes, allowance being made for loss by friction. Hence it follows that, to diminish this pressure, we only need to lengthen the distance GH, which is easily done by changing the position of the axis GG′, on which the lever turns; by shortening this distance, the pressure is, of course, increased.

In the present day, the uses of the hydraulic press are very various: it is used to extract the juices of certain plants, such as olives and grapes; the oil from seeds such as linseed, rape-seed, and castor-seed; to press paper, stuffs, and forage intended to be sent to great distances, and which, thus compressed, occupy much less space than before the operation; it is also employed in the manufacture of wax candles, vermicelli, &c. Iron chains and cables for naval use, and girders are submitted to tests in order to prove their resistance to strain, and these tests are applied by the hydraulic press.

The same machine has been employed to raise enormous weights to great heights. In this way the four immense iron-plated tubes forming the gigantic Britannia Bridge, which carries the railway from Chester to Holyhead across the Menai Strait, was raised to the top of the piers. Nearly two millions of kilogrammes were thus raised to a height of thirty-three metres by steam-driven hydraulic presses.

We may next refer to a recent and very ingenious modification of the first form of the hydraulic press. This form suppresses the force-pump which transmits pressure to the piston of the large press P,

and replaces it by the introduction of a metallic wire or rope. The wire or rope, which is thus introduced by means of traction into the body of the press, conveys to the incompressible liquid in the latter the force necessary to introduce it, and this pressure is multiplied, as in the common hydraulic press, in the ratio of the sectional area of the large piston and of the wire. But how is the wire introduced?

In the body of the press (Fig. 15) is a bobbin worked from the outside by means of a handle; round this the wire is gradually coiled from another exterior bobbin. By degrees the wire is introduced into

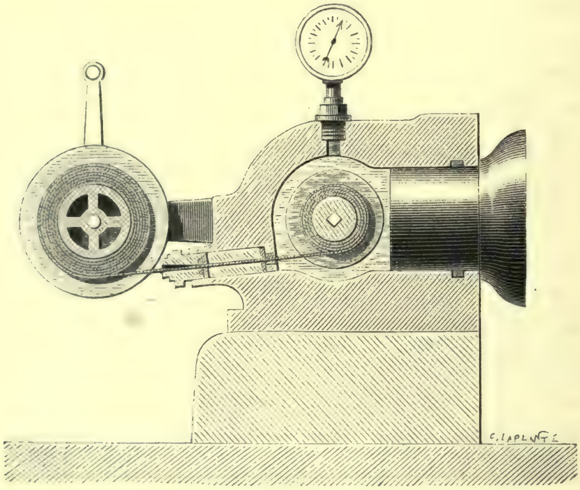

FIG. 15.—MM. Desgoffe and Ollivier's "sterhydraulic" press.

the liquid (generally oil) which the body of the press contains. The liquid is thus displaced, and the pressure exerted, in order to make room for the displaced liquid, is transmitted equally to every part of the sectional area of the piston equal to the section of the wire.

In this new arrangement invented by MM. Desgoffe and Ollivier there are two distinct advantages. In the first place, the compressing power is considerably increased, as it is possible to give the wire a much smaller diameter than that of the piston of any possible force pump, on account of the breakage which would inevitably occur in the case of a metal rod, if its dimensions were too small. Secondly, the introduction of the wire in the sterhydraulic press is made

by winding round interior and exterior bobbins; the movement is therefore continuous, whilst in the ordinary press the compression is effected by successive strokes. But by the side of those advantages there are inconveniences, which M. Tresca thus sums up in an otherwise favourable report to the "Société d'encouragement pour l'industrie nationale":—

"To make room for the interior bobbin, a much larger capacity must be given to the body of the press; to transmit the movement an aperture must be made for the arbor, and this aperture must be furnished with a very thick tow casing; the same remark also applies to the aperture by means of which the wire is introduced, which must not allow any liquid to ooze out, as otherwise the press might be emptied and great diminutions of pressure take place during the working."

According to M. Tresca, the use of this new press would be especially advantageous in smaller mechanical operations. In great undertakings however serious difficulties would be met with in its use.

§ II.—Areometers or Hydrometers.

The story of Archimedes coming out of his bath and running through the streets of Syracuse, crying out, Εὕρηκα, εὕρηκα, "I have found it! I have found it!" is well known. He referred to a problem which King Hieron had desired him to solve. It was necessary to determine whether in a crown delivered to this tyrant by a goldsmith, as pure gold, any other metal had been introduced. The discovery of the principle of hydrostatics, which is named after the immortal geometer, put him in the way of accomplishing this, and he discovered that a certain quantity of silver had been mixed with the gold in the making of the royal diadem. It is said that Archimedes made little use of the practical applications of geometry and the sciences; but he was far from neglecting them: numerous inventions of this kind are on record due to his genius. To him is attributed the invention of areometers or hydrometers, instruments based directly on the principle that all bodies immersed or floating in a liquid displace, when equilibrium is established, a volume of liquid

having precisely the same weight as the weight of the body; it is this same principle, discovered and demonstrated by Archimedes, which made the solution of the problem of the crown easy. Other scientific historians have considered the discoverer of areometers to be the beautiful and learned Hypatia, the unfortunate victim of the religious fanaticism of the Alexandrian monks. What is certain is that these valuable little instruments owe their actual form to a modern physicist, Homberg.

We have described the areometers specially adapted to measure the density of bodies with the most perfect scientific accuracy (see *Forces of Nature*). It now remains for us to speak of the use made of similar instruments in the arts and manufactures in those cases in which the principle of Archimedes is utilized to determine the composition of certain mixtures.

They are generally cylindrical glass rods, weighted at the lower end by leaden shots or mercury, enclosed in a globular appendage. The weight of an instrument thus constructed is invariable, hence the name of scale-hydrometer in opposition to weight-hydrometers; the immersed part sinks lower as the liquid is less dense, because the liquid displaced always has a weight equal to that of the instrument.

Pure water is the liquid used for comparison: the zero of graduation is made at the point of the stem which touches the surface. Instead of making one graduation only for liquids or mixtures denser or lighter than water, it has been found more convenient to construct two kinds of hydrometers for the two series, the zero being in one case at the top, and in the other at the bottom (see Figs. 16 and 17).

Fig. 16 represents Baumé's hydrometers which, according to the uses to which they are put, are called alcoholometers, salimeters, acidimeters, saccharometers, and vinegar hydrometers, because they are employed to determine the greater or less concentration of these fluids.

Thus in the salimeter the zero lies at a point at the upper extremity of the stem. Immersed in a solution containing 15 parts by weight of sea-salt and 85 of water, the hydrometer sinks to a lower point, marked 15; the division of the interval from 0° to 15° in fifteen equal parts, and continued to the bottom of the stem, furnishes the graduation.

The extreme point of Baumé's salimeters is 60° : the hydrometer floats with this point at the surface in monohydrated sulphuric acid ; 36° corresponds to nitric acid and 26° to hydrochloric acid.

The alcoholometer, called also alcohol hydrometer, spirit hydrometer, and ether hydrometer, is intended to compare liquids of less density than that of water. It is constructed so that, immersed in pure water, the point to which it sinks is near the bottom of the stem (Fig. 17). The graduation starts from zero at this point: on placing the hydrometer in a solution containing 10 per cent. of sea salt, the difference between the two levels is divided into ten equal parts (degrees), and this scale is continued upwards from zero to

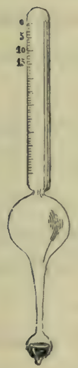

FIG. 16.—Hydrometer for liquids heavier than water.

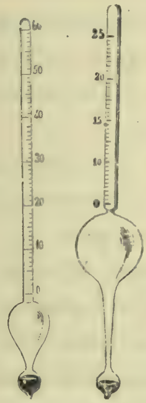

FIG. 17.—Hydrometer for liquids lighter than water.

FIG. 18.—Gay-Lussac's centesimal alcoholometer.

about 50°: this scale is sufficient for the requirements of industry and commerce.

The expressions: alcohol at 36°, alcohol at 40° indicate that Baumé's alcoholometer, immersed in an alcoholic or spirituous liquid, sinks to the divisions 36 or 40 of the hydrometer thus graduated.

Hydrometers are constructed to determine the richness of wine in alcohol: these are called vinometers ; others to discover if milk does or does not contain water: these are termed lactometers.

Gay-Lussac's centesimal alcoholometer (Fig. 18) has a great advantage over that constructed by Baumé: its graduation not only indicates the comparative strength of pure alcohol and water in

alcohol, it shows in hundredths the proportion of the volume of the spirit to that of the water. Thus, when the instrument immersed in a mixture marks 70°, it shows that this mixture really contains 70 parts of pure alcohol and 30 parts of water.

Gay-Lussac, in order to graduate this hydrometer, immersed it successively in mixtures containing 0, 10, 20, 30 . . . . 100 parts of pure alcohol, a delicate and laborious operation, because the mixture of the two liquids produces a lowering and a rise of temperature, so that it was necessary to wait until the mixture had cooled to a uniform temperature (that of 15° C.) and to calculate the new proportion of the two volumes.

In the United Kingdom spirit is valued for revenue purposes according to the quantity which it would make if brought, by the addition or abstraction of water, to a strength termed "proof":—proof-spirit being defined by law (58 G. iii. c. 28) to be such spirit as at the temperature of 51° Fahrenheit shall weigh $\frac{12}{13}$ of an equal measure of distilled water.

Sikes' hydrometer and its accompanying tables are the means adopted for the purpose of ascertaining the strength of spirit, and calculating the quantity at proof for the purposes of revenue in this country. It acts, like the saccharometer, upon the principle of weighing the bulk of liquid displaced by the instrument when floating in it.

Fig. 19.—Syke's Hydrometer.

The instrument consists essentially of the following, as shown in the diagram:—B C is a hollow brass ball, surmounted by a flat stem, A B, and loaded below by a short conical stem, C D, terminated by the pear shaped bulb D.

By means of nine weights, ten principal divisions on the stem, and five subdivisions to each, it has a scale divided into five hundred parts, and ranges from a strength of 70 per cent. over-proof at 47° Fahrenheit, or a density of ·8156, down to water, or density ·1000. One of these weights, W, is represented above. It (the weight) is furnished with a slit, so as to allow of it being slipped on to the narrowest part, C, of the lower stem.

The instrument is so adjusted that it indicates the volumes of water that must be added to or taken from 100 volumes of the

mixture subjected to examination, to reduce it to proof-spirit. Thus if the instrument indicates 10 over-proof, 10 volumes of water must be added to bring the liquid down to proof strength, and 100 gallons of such strength would be reckoned as 110 ; in the same way 100 gallons at 10 under-proof would in the same way be charged at 90 The indications of the instrument referred to are of a perfectly arbitrary character, and reference must be made to the tables to ascertain the proportion of spirit they represent. It may be remarked generally, however, that these indications commence with zero at the highest strength, and that, upon an average, every subdivision of the scale shows a diminution of three-tenths per cent. of proof-spirit. This instrument is therefore greatly more exact than the continental one, which indicates only differences of one per cent. Corrections on account of temperature are provided for by tables wherein Sikes has made the correction for each degree between 30° and 80° Fahrenheit.

The centesimal alcoholometer is officially adopted in France for testing brandies, spirits, and all alcoholic liquors. In Germany Trelle's alcoholometer, which only differs from that of Gay-Lussac's by the temperature of the graduation (60° Fahr. or 15°·5 C.), is employed.

It is important to remark that the different instruments described here enable us to determine the density of the liquid mixtures in which they are immersed only indirectly. Tables however have been calculated giving the density for each degree. But they give no information as to the composition of the mixture which may be changed from its normal composition by the introduction of foreign substances.

§ III.—Water-levels.—Spirit-levels.

The free surfaces of liquid in communicating vessels when in equilibrium lie in the same horizontal plane. This fundamental property of liquids has been utilized for making a very simple instrument, used in levelling operations. This is called the water-level. It is composed of a long metal tube *b b*, the two ends of which are bent at a right angle, vertically supporting two glass vessels open at the top. To use it, the tube is filled with water, so that the liquid nearly fills the vessels, when the tube is arranged horizontally.

The line of sight along the two surfaces of the water in the vessels, provided that the diameters of the glass tubes be exactly the same, will be horizontal. By turning the instrument on its axis in another direction, the new line of sight will be likewise horizontal and in the same plane as the first.

By a series of experiments, which it is not necessary to describe here, those portions of land-surface on the same level can be determined; in other words, *contour lines* can be drawn with great accuracy and rapidity.

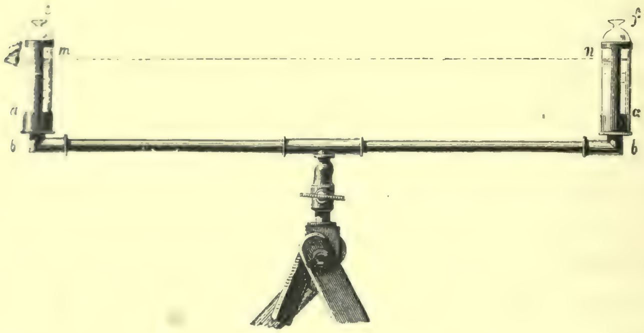

FIG. 20.—Water leve

Spirit-levels, like water-levels, are used to determine the horizontality of a line or plane; but their construction is based on a different physical principle.

Imagine a closed glass tube in a metal mounting, which leaves a part of the tube visible (Fig. 21). It is entirely filled with a liquid —water, alcohol, or ether (these last are preferable to water, because

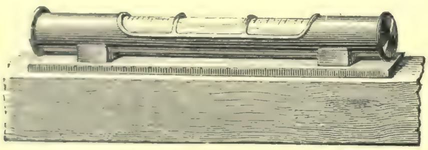

FIG. 21.—Spirit-level.

they do not freeze)—with the exception of a very small space filled with a bubble of air or vapour. By virtue of the law of equilibrium of fluids of different density, the gaseous bubble will always be found

at the highest point of the tube. If we place the tube on a metal plate inclined towards the horizon, the bubble will rise to the highest end of the tube: it will only remain exactly at the middle point if the tube and the plate be in a perfectly horizontal plane; the slightest inclination in one direction or the other brings it to one or other of the extremities of the tube; to obviate this inconvenience, the tube is slightly convex at its upper part, so that the movement of the bubble is more rapid and decided towards this point. The horizontality of the plane of the plate is perfect when the bubble, after a few oscillations, remains so that its extremities occupy the same divisions on either side of the centre of the convex top of the tube.

To make a surface horizontal it is supported on three points arranged at the angles of a triangle by levelling screws (Fig. 22): first a true level is obtained parallel to one of the bases of the triangle, and by properly moving one of the two screws, the first

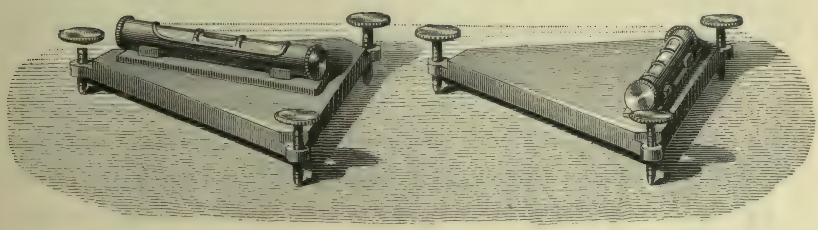

FIG. 22.—Horizontal of a plane obtained with a spirit-level.

horizontal line is obtained. Then placing the level at right angles to its first position, the third screw is used to obtain horizontality in the new direction. The plane of the surface is then necessarily horizontal, as two lines at right angles which are horizontal lie in it.

When spirit is employed instead of water, much more accurate observations are obtained; hence spirit is used in preference in geodetic experiments and in levelling operations of importance, such as the attachment of a level to an equatorial telescope to enable it to be used as a transit instrument. All instruments of precision in which certain portions must retain an exactly horizontal or vertical direction during the observations are furnished with spirit-levels.

§ IV.—Artesian Wells.—Fountains.

The construction of artesian wells is also based on the principle of the equal height of liquids in communicating vessels. It is true that this condition is not the only one to be inquired into, and that knowledge of the geological strata and of deep springs is also indispensable. But we shall confine ourselves, in what we shall say relating to this important scientific application, to the point touching the corresponding chapter of physics.

Long before science had attained its present accuracy, fountains or artesian wells existed. The ancient Egyptians and Chinese knew how to bore wells whence the water rose and came out in the form of jets or flowing rivulets. In France, the ancient province of Artois long ago possessed wells of this kind, and hence the origin of their name. Theory accounts for their occurrence in this way:—

If we take a tube with two arms curved like a U, the water poured into one of the branches runs into the other, and, as soon as equilibrium is established, the level of the water is the same at *a* and *b*, that is, in both of them. Let us now suppose that one of the branches is shorter than the other and closed by a cock—that the longer branch is surmounted by a reservoir full of water. If the level *c* of the water in this exceeds the distance by *c d* the level at the top of the shortest arm, the liquid will exercise a pressure on the bottom equivalent to the weight of a column of water of the height *c d*; so that if by opening the cock this pressure be permitted to exert itself freely, it would force out the liquid to a height which would be equal to *c d*, if the resistance which friction against the sides of the tube and the air displaced by the jet opposes to its movement be regarded; we must suppose also that the reservoir has such a capacity (if it be not fed by a constant source) that its level does not itself vary to any perceptible degree during the experiment.

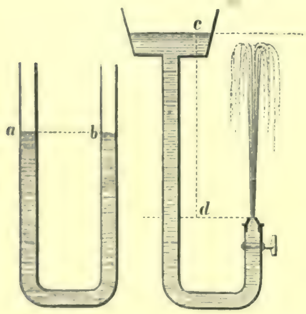

Fig. 23.—Principle of fountains and artesian wells.

We see, too, that on this property of the equilibrium of liquids in communicating vessels the construction of artificial fountains which adorn parks, gardens, and public places, &c., as well as natural springs themselves, depend.

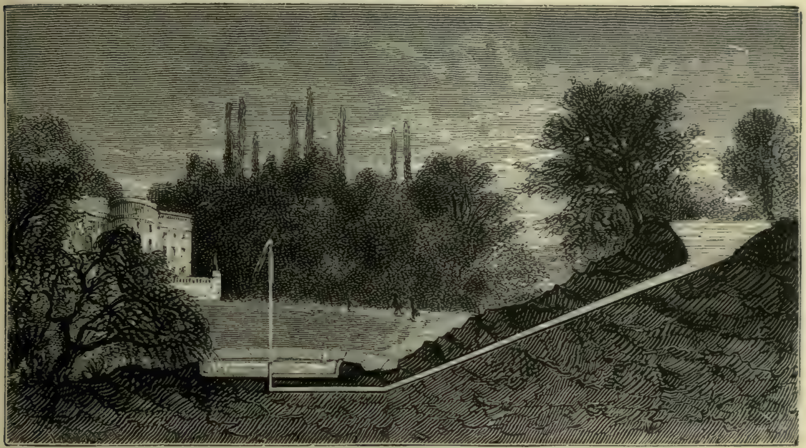

FIG. 24.—A fountain.

Now an artesian well is nothing more than an aperture made through the upper strata of the earth and descending to different depths, according to the geology of the district, to search for sheets of subterranean water imprisoned by beds impenetrable to water. These

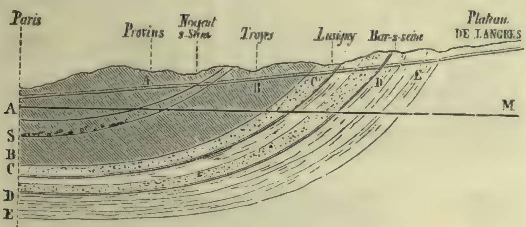

FIG. 25.—Geological section of the basin of the Seine, between Paris and Langres

sheets of water follow the windings and inclinations of the strata ; it is necessary, in order that the water should rise in the wells, that there be between the point attained by the boring and the level of the sheet of water a certain difference of height. An example of this fact

is seen in the geological section of the strata which constitute the Paris basin, stretching from Paris to the upper level of the basin, at the plain of Langres. The beds of water-bearing sand which are met with at depths of 548 and 570 metres, in the case of the borings of the

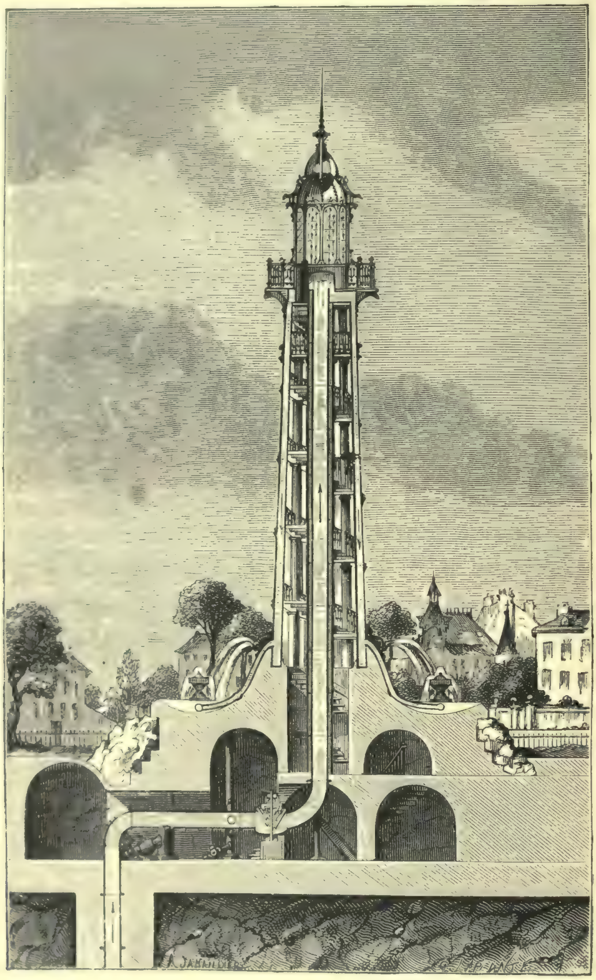

FIG 26.—Artesian well at Passy

artesian wells of Grenelle and Passy, are covered by a series of rocks, principally a bed of chalk of considerable thickness. All these layers, gradually rising to the surface, come out at points by so much

the more distant as their depth is greater. The water-bearing sand does not show itself nearer than the plain of Langres. Along the whole extent of the basin where this cropping up to the surface takes place, the sand-beds receive the rains which filter and descend through their whole depth, thus constituting a succession of immense curved tubes in which the water is more and more compressed. It is easily seen therefore that in boring a well at a point where the altitude is lower than that of the surface which receives the rain, the water will rise in the well and will spout out above the ground as soon as the depth of the boring is sufficient to reach the water. At Passy, the water rises, as shown in Fig. 26, to a very considerable height, the delivery being not less than 17,000 cubic metres in twenty-four hours.

The process of boring, although it is in the present day greatly improved, does not prevent serious difficulties being encountered, when artesian wells have such great depth as those of the Paris basin just mentioned. If the drills, the boring bits, or their rods (which are the tools used to bore the rocks and draw up the débris to the surface) happen to break, it often requires very long and expensive operations to free them.[1]

§ V.—The Pipette.—The Magic Funnel and Inexhaustible Bottle

We described, when dealing in the *Forces of Nature* with the Syphon, an interesting and useful experiment, showing how the pressure of air might be brought to bear on the flowing and decanting of liquids. The pipette is a little instrument answering a similar purpose. It allows us to draw into another vessel a portion of liquid contained in a vessel which we are unwilling to disturb. It is a tube with a tapering end of tin or glass; this is immersed in the liquid, and is filled either by simple communication or by aspiration.

Once full, the pipette is held as is shown in Fig. 27, by placing the finger on the upper opening; then on withdrawing it from the vessel, the atmospheric pressure which is exercised on the liquid at

[1] For a detailed description of the boring of an artesian well, we must refer to special works, among which is the *Guide du Sondeur*, by M. Degousée, and *L'Hydraulique*, by M. Marzy (*Bibl. des Merveilles*).

the taper end is sufficient to hold it in the tube; but if the finger is raised and air is admitted, the exterior pressure on the inner surface at once counterbalances that on the lower level of the liquid, and the liquid flows out by its weight.


FIG. 27.—Pipette.

It is also possible to stop the efflux of the liquid or recommence it at pleasure by the simple movement of the finger. This is done by those who show amusing physical experiments with the magic funnel or the inexhaustible bottle. We can easily account for the working of these.

Fig. 28 represents the magic funnel. It is a double funnel, the inner and invisible cavity is filled with a liquid,—wine, for instance. A small opening, worked near the handle, is closed or opened with the thumb, and a small inner hole connects the cavity full of liquid with the visible inner tube of the funnel. When the thumb is lifted, the wine runs out. The flow of the liquid ceases at the will of the operator, if he closes the upper opening.

If water is poured into the visible space of the funnel, pure water will flow out, or a mixture of water and wine, according as the


FIG. 28.—The magic funnel.

opening of the handle shall be closed or open. The spectators then believe that water or wine may be made to flow from the magic funnel at pleasure.

The inexhaustible bottle is a bottle of many compartments, each of which is filled with a different kind of liquid. Each compartment communicates with the exterior by a small hole worked through the side of the bottle, which the operator opens or shuts at pleasure with the fingers. He can then pour out the kind of wine that he

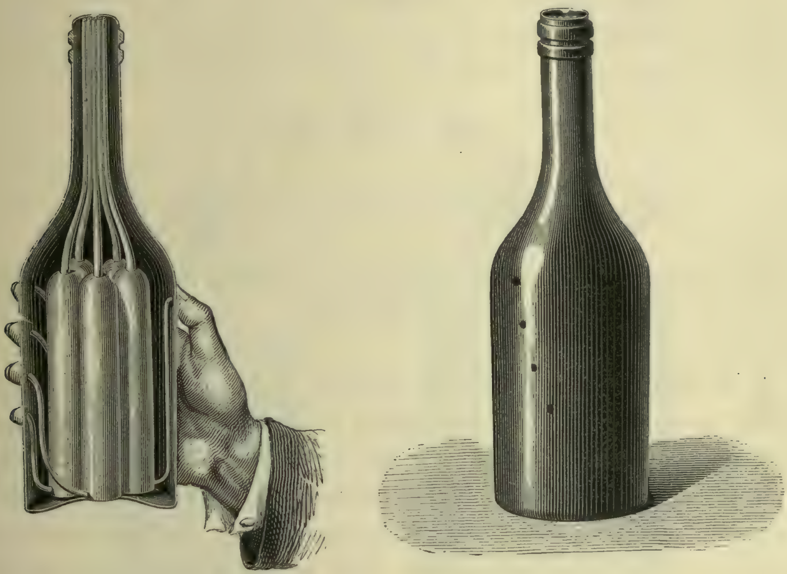

FIG. 29.—The inexhaustible bottle.

pleases or that the spectator asks for, or even make a mixture by pouring out two or three liquids at a time.

These amusing physical experiments are principally based on the action of atmospheric pressure, of which we will now study the more serious and especially the more useful applications.

CHAPTER III.

PUMPS.—ATMOSPHERIC RAILWAYS AND LETTER TUBES.

§ I.—PUMPS.—ATMOSPHERIC PRESSURE EMPLOYED IN THE ELEVATION OF WATER.

A PUMP barrel, or cylinder, in which a piston causes a vacuum by an up-and-down movement; a pipe of more or less length, communicating at one end with the lower part of the body of the pump, and at the other with a reservoir of water or a well, in which pipe the air is rarefied at the same time and by the same action as the air in the body of the pump. Such are the principal parts of the suction-pump as it is used in numerous instances, and principally for domestic purposes. The principle on which the raising of the water depends is, as indicated in the *Forces of Nature,* that of atmospheric pressure, which exercises its whole force on the surface of the water in the reservoir, whilst it is *nil,* or at least reduced, in the interior of the pipes and in the portion of the pump situated below the piston.

Fig. 30 shows how a pump of this kind is generally fixed above a well when the depth of the well is less than 7 or 8 metres below the point where the water flows from the pump. It will be seen by examination of the drawing how the up-and-down motion of the piston first exhausts the air in the cylinder and then continues to raise the water. In the piston is a *valve,* or in other words a *door* opening upwards only; at the bottom of the barrel is a similar valve which also only allows a passage in one direction. When the piston descends, the air or water in the barrel is compressed between it and the bottom valve, and not being able to escape downwards it passes

upwards through the piston. When the piston rises the valve which it contains closes, the fluid above it is lifted up and a vacuum is produced in the barrel which is immediately filled by the fluid in the pipe raising the lower valve and rising into the barrel. Theoretically, the water ought to rise in the suction-pipe to a height of 10·33 metres when the barometric pressure is 760 millimetres; but, in reality, the rise is much less, as the apparatus does not act with the perfection which is necessary. There are escapes at the joints,

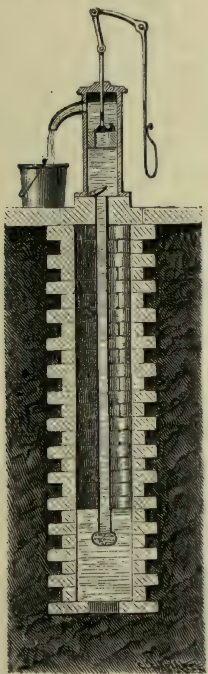

FIG. 30.—Suction-pump.

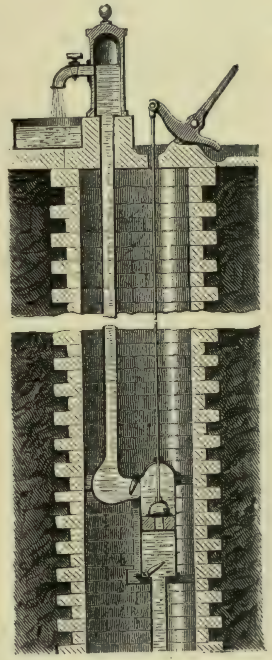

FIG. 31.—Suction and Force-pump.

moreover, the water contains air in solution, in the form of bubbles, which destroys the vacuum. The movement of the water itself, the friction of the liquid against the sides and its disturbances, causes losses of power, and the height to which it can be brought is very often reduced to the 7 or 8 metres of which we have just spoken.

If the depth of the well is greater, the suction-pump is not sufficient; its action is completed by an arrangement which forces the water to a greater height, and thus conducts it from the point

whither it is brought by suction to the place where it is required. The pump is then both a suction and force-pump. In Fig. 31 is shown the kind generally adopted for deep wells. It is simply a force-pump, the pump-barrel of which is fixed in the interior of the well at a sufficient depth for the water to be sucked into it in the manner just described. Thence it is forced up at each upward movement of the piston into a reservoir, also placed in the interior of the well, and into a pipe which connects this reservoir with the exterior part of the pump. When the piston descends, the weight of the water closes the upper lateral suction-valve; this prevents the return of the water into the pump-barrel. In this manner, after a certain number of strokes of the piston, which are necessary to fill the machine, the water is poured out intermittently by the tap. It is clear that this arrangement will enable water to be forced to any height—to raise it, for instance, to the different floors of a house.

Numerous and various forms and arrangements are given to pumps and the different parts which compose them, the detailed description

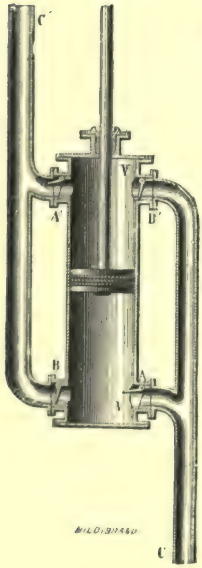

Fig. 32.—Double action pump (section).

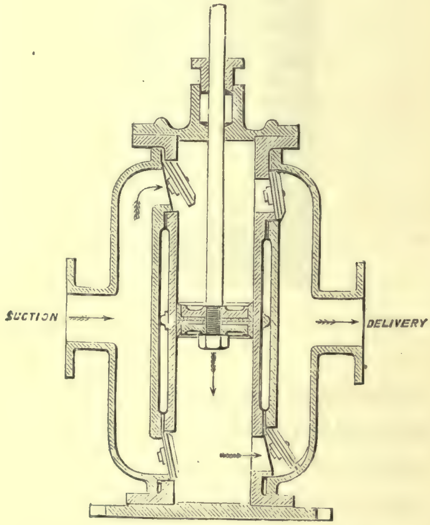

Fig. 33.—Another form (Owen's) of double action-pump (section).

of which would occupy volumes; but these details, which are all based upon the physical principle to which we have referred, would

not present any interest here. Sometimes these modifications depend upon the particular employment of the pumps; in other cases, they result from the way in which the inventor has re-arranged them to remedy some particular inconvenience, or to obtain some special advantage. In order to avoid the intermittence of the jet, double-action suction and force-pumps are sometimes constructed. These are arranged so that the suction and the forcing of the water is done at the same time, both during the rise and fall of the piston. In these machines, the piston is solid, and the body of the pump is pierced with four openings, furnished with valves, as shown in Figs. 32 and 33. During the ascending movement of the piston, the valve A is opened, and a certain quantity of water is introduced by suction into the lower part V of the pump-barrel; the valve B is closed by that which the forcing-pipe C′ already contains; on the other hand, the valve A′ is opened, and gives passage to the water contained in V above the piston; and this water is forced towards C′; finally, the pressure of this water shuts the valve B′. During the descending movement of the piston, the parts act in an opposite direction: the valves A and A′ are closed, B and B′ are open, so that the water is sucked up at the top and forced up at the bottom. The jet is then nearly continuous; but it is easy to understand that the working of the lever-beam or handle requires double strength. This kind of pump is specially used for draining purposes, and in that case a

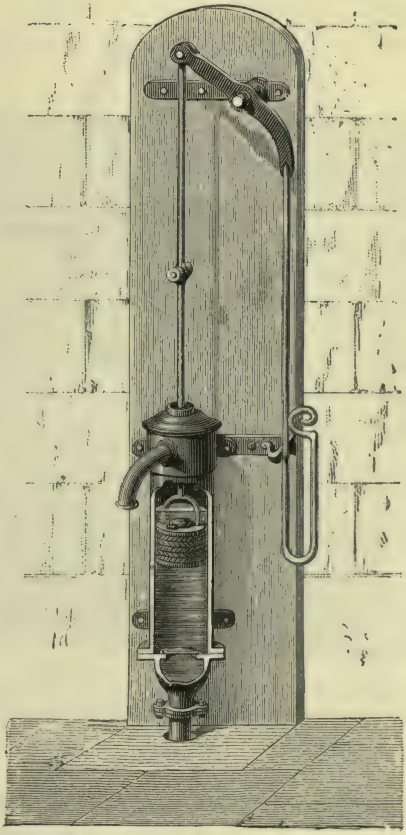

FIG. 34.—Common pump, with handle and lever.

handle or beam is fixed to the machine, worked by two or several men, or the pump is driven by a crank connected with a steam-engine.

The kind of motive power which gives the up-and-down movement to pumps may also be very various. Ordinary pumps, intended for domestic purposes, and of small sizes, are fitted with levers, oscillating on a fixed point, moved by the arm or by a wheel turned by the same means.

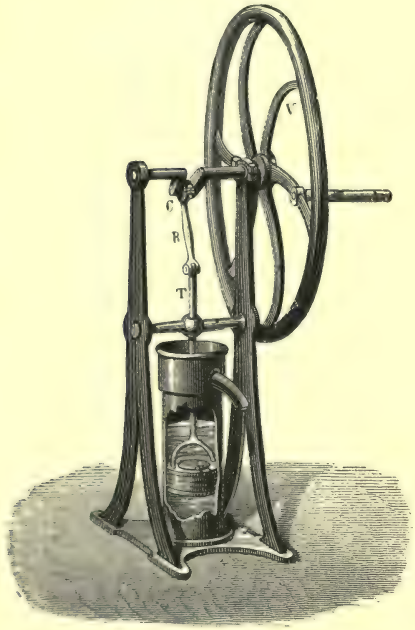

FIG. 35.—Pump with crank and fly-wheel.

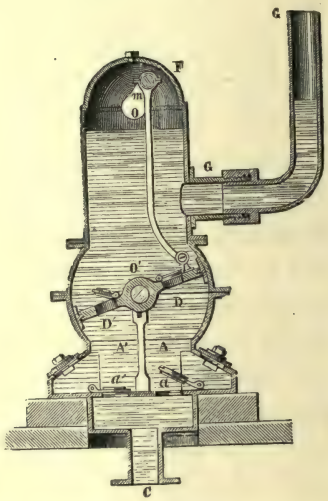

FIG. 36.—Bramah's oscillating pump.—C, a, a', suction tube and valves.—A, A', spaces separated by a partition.—DD', piston oscillating round the axis O'.—Om, handle giving movement to the piston.

But when more considerable strength is required for powerful pumps, the motive power is sometimes a horse-power machine, sometimes steam, and sometimes the force developed by a fall of water. The elevating machine at the bridge of Notre Dame, pulled down several years ago, was a pump moved by means of hydraulic wheels fixed at a point of the Seine where the rapidity of the current gave a considerable disposable force. In the old machine at Marly, which raised the waters of the Seine to the royal castles of Marly and Versailles, by giving motion to 221 pumps, fourteen were of the same

kind, hydraulic wheels being used. At the present time, the new wheels, only four in number, and each setting in action four horizontal pumps, furnish a quantity of water much greater than that given by the old machine. This may serve to give an idea of the perfection now arrived at in mechanical constructions during the last two centuries. The Chaillot pumps are moved by steam. A steam-engine, established 100 metres from the banks of the Seine, also works the pumps supplying water to the town of Fontainebleau. The immense draining works undertaken in Holland have been a long

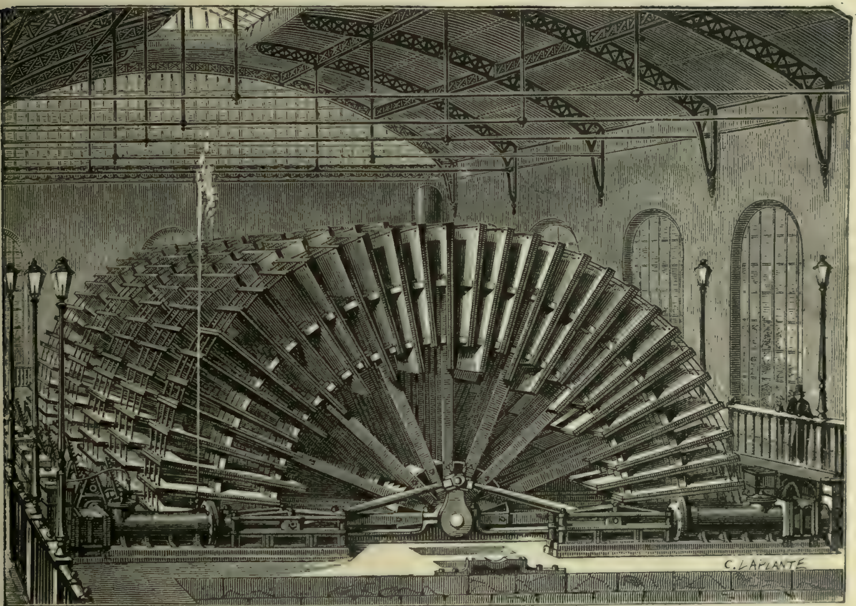

FIG. 37.—The new water-wheels and pumps at Marly.

time worked by pumps, with wind for motive power. In 1840, more than 2,500 windmills were still used for this purpose. At the same time the draining of the Lake of Haarlem was undertaken with the help of a steam-engine of 350-horse power, which worked eleven pumps. The mean clearing was 475,000 cubic metres every twenty-four hours.[1]

[1] For more details on works of this kind, undertaken by the aid of pumps or other similar machines, the interesting work of the *Bibliothèque des Merveilles*, on *Hydraulics*, by M. Marzy, may be consulted.

In the pumps used in large hydraulic works, the different parts must necessarily be constructed with great solidity, on account of the considerable pressure and resistance to which they are subjected. The piston is then generally a massive metal cylinder, as represented in Fig. 38. It is then called a plunger. It will be seen that on each side of the pump-barrel is a valve, opening upwards. One of these, to the left of engraving, admits water into the barrel while the plunger is making its upward stroke, while the other opens as soon as the plunger begins to descend, and allows the water to escape into the delivery pipe.

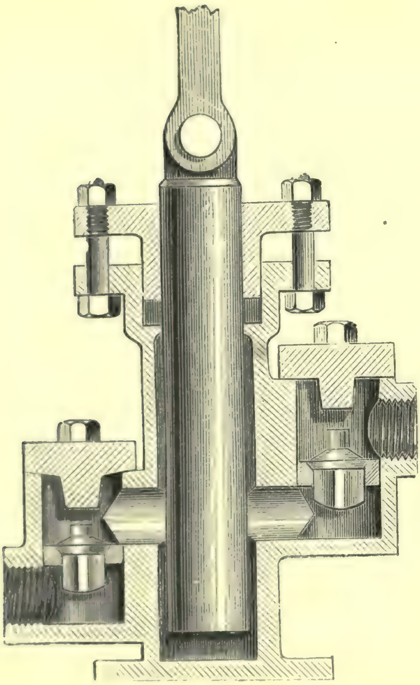

FIG. 38.—Plunger pump.

The mechanism which draws up the water in suction pumps is not always a piston moved alternately upwards and downwards in a cylindrical body, and making the vacuum from the side of the pipe which brings the liquid. In certain pumps called oscillating pumps, there is a fixed blade, oscillating on an axis, which acts as piston, and both sucks up the water by causing a vacuum by one of its arms, whilst it presses the water already brought by the movement of the other part. Fig. 39 represents a Bramah's oscillating pump, and clearly shows the action of the movable piece and valves.

In rotatory pumps (Fig. 39 gives a cut of Stoltz pump) the suction pipes C and forcing pipes C′ are connected by two openings a and a', with a circular drum A, in the interior of which a ring, concentric with the drum B, is in motion. Four blades p, p, p, p, rest both on the interior surface of the drum and on the surface of an eccentric; closing hermetically the circular space, and consequently producing the

vacuum behind them by pressing the water forward, thus acting as so many pistons.

Behrens' rotatory pump (Fig. 40) which works also as a steam-engine (see chapter devoted to steam-engines), is a much more simple construction. Any motive power, steam for instance, puts in motion an arbor which, by a system of cogged wheels, moves in contrary directions the axes C, C′ of two pistons. These turn in the interior a drum communicating with the suction-tube B and the ejection-tube D. Each piston E, E′, has the form of a portion of a massive crown which leaves free a circular space a, a'. When this space falls opposite the suction orifice, the piston E by its movement increases more and more the free space behind it; a vacuum is gradually developed, and a certain quantity of water fills it.

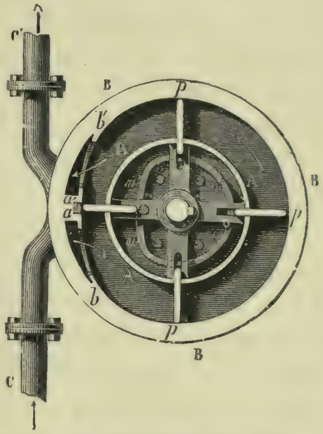

FIG. 39.—Stoltz's rotative pump.

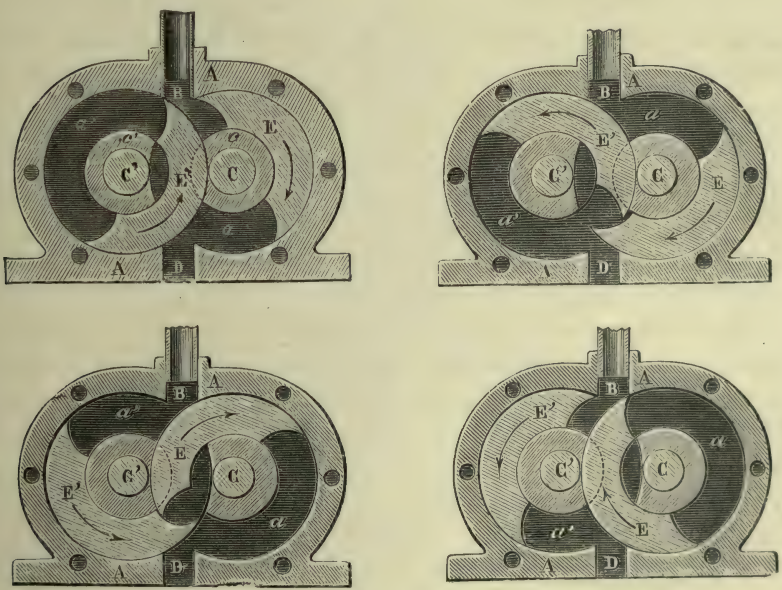

FIG. 40.—Behrens' rotatory pump: phases of the rotatory movement.

During this time, the other piston ejects through the conducting pipe the water already inside. At each half turn the two pistons change their functions; that which drew up ejects and *vice versâ*, so that the pump is to a certain extent a double-action pump. The double action is easily seen by examining what happens during an entire rotation by comparing, for instance in Fig. 39, the respective positions of the pistons and the spaces a, a', after each quarter turn.

Perhaps the most important form of rotating pump is that known as the centrifugal. There are several varieties of this system, but the principle on which they all act is identical. The pump consists of a circular chamber in which revolves with great rapidity a wheel or fan, the arms of which curve outwards, so that all the air or water contained in the chamber is driven by the so-called "centrifugal force" away from the centre. The delivery pipe is therefore placed at the circumference of the chamber and the fluid is sucked in at its centre. It will be seen that these pumps do not produce a complete vacuum, and therefore are not suitable for drawing water long distances; but owing to their simplicity they are of great use for raising large quantities of water a short distance, as, for example, in draining marshy lands. They are generally driven by steam power.

It only remains for us to complete all that relates to this head, to speak of force-pumps, although as we have before stated, their construction is by no means based on the principle of the action of atmospheric pressure.

§ II.—Fire-engines.

Fire-engines and pumps used for watering gardens are of the kind we have defined as force pumps.

Hand fire-engines (Fig. 41) are generally composed of two force-pumps joined together, and connected with a reservoir, which is filled, either by pails (and the formation of a chain of men to pass them) or by pipes connecting them with the water supply of towns. They are worked by a lever to which are attached the rods of the two pistons. These move in contrary directions, so that the water is forced continuously into the space in which the ejection piston descends This space contains air, which, being compressed by the water with which it is continuously supplied, exercises a pressure on the liquid;

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THE STEAM FIRE-ENGINE AT WORK

it is therefore named the air-reservoir. The velocity with which the water escapes from the hose depends on this pressure, and as this only varies slightly if the air-reservoir is of sufficient capacity, it follows that the discharge from the jet is nearly constant.

A steam fire-engine consists of a steam-engine, pump, and boiler, fixed to suitable framing, and mounted on wheels and springs. There is a box to contain hose and implements, which also serves as a seat for the firemen and driver. The whole machine is of the lightest possible construction consistent with strength and durability, and is readily drawn by a few men, or, for greater distances, by a pair of horses.

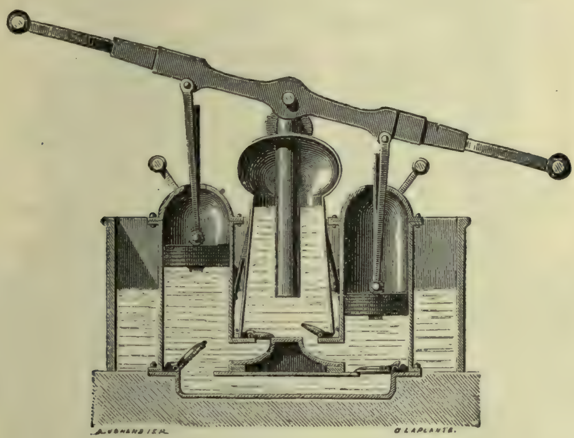

FIG. 41.—Hand fire-engine with lever.

Steam fire-engines comprise three classes: Land, Floating, and Fixed. The appearance of the Land steam fire-engine is now familiar to all the dwellers in our large towns, most of whom have seen it in its rapid progress to a fire, drawn by horses, and carrying its complement of firemen with hose and implements.

Floating steam fire-engines are a desirable acquisition in ports and docks, where warehouses and stores of goods are in proximity to water. They are made self-propelling, or are placed in a vessel to be moved about by steam-tugs.

Fixed steam fire-engines are placed in manufactories, or other places where steam boilers are already in use, the steam from which is available both day and night for working the engine.

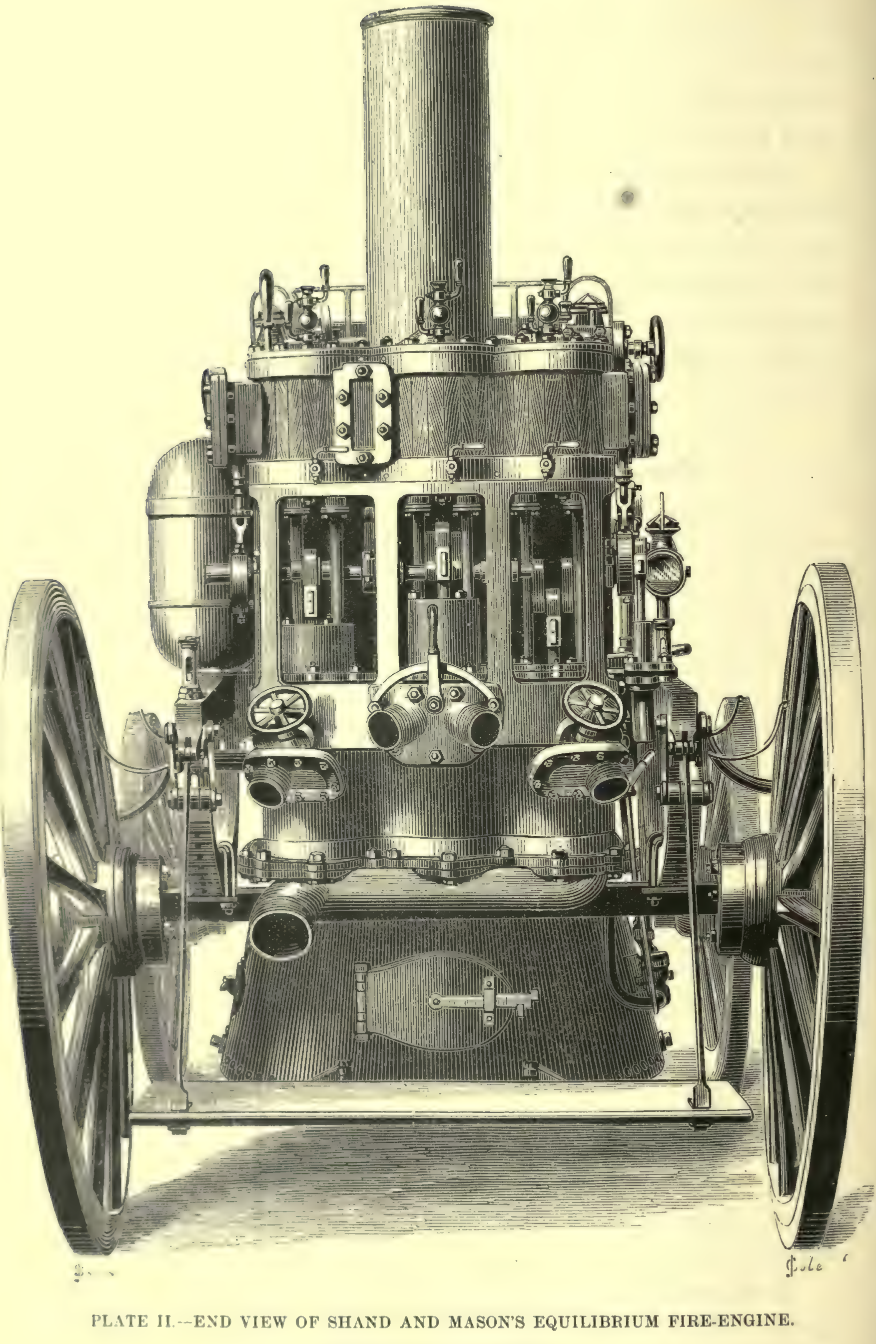

PLATE II.--END VIEW OF SHAND AND MASON'S EQUILIBRIUM FIRE-ENGINE.

Cylinders above, Pumps below.

The best steam fire-engines of all descriptions are those in which the force-pumps are direct acting, the steam- and water-pistons being connected by rigid rods, without the intervention of any joint, so that the force communicated by the steam to the steam-piston is instantaneously transmitted to the water-piston without any shock or blow.

We give in this place a drawing of one of the most powerful steam fire-engines known—Shand and Mason's Equilibrium fire engine. The special arrangements of the pumps will be seen from the accompanying woodcut. For these engines it is important that steam should be got up at once. In the "equilibrium" engine, by means of a special arrangement of boiler, to which we shall refer hereafter, steam of 100 lb. pressure can be got up in 6½ minutes. Great economy of steam, and consequently of boiler space and fuel, is thus obtained, and the weight of the whole machine is greatly reduced.

The engine will throw a jet through a 1½-inch nozzle 130 feet high, throwing in 17½ minutes nearly 7,000 gallons of water.

The equilibrium steam fire-engine is fitted with a set of treble pumps, worked directly by a corresponding treble set of steam-cylinders, by the use of which a perfect uniformity is obtained in the flow of water through the hose- and suction-pipes, avoiding all shocks to the engine or pipes, and producing jets quite as steady as those obtained by pressure from gravitation. The use of the three steam-cylinders, besides securing the above advantages, enables the fly-wheel to be dispensed with, but the crank and rotary motion is retained, as all other substitutes have failed in securing a fixed length of stroke of piston.

In the horizontal fire-engine the arrangements are somewhat different. They will be understood from the accompanying section, p. 62.

C, a slotted cross-head formed by the ends of the piston-rods of steam- and water-cylinders, and containing the sliding bearings of the crank D, to which it communicates a rotary motion; L, the auxiliary cylinder, with its piston M, fixed on A, the slide-valve rod; H, the slide-valve of the main cylinder, the frame of which moves the slide-valve K of the auxiliary cylinder; N, a ratchet lever to enable the engine to be moved round by hand.

B^1, the valve-box cover of the water-cylinder, which, when removed, allows the four India-rubber valves with their seats and guards to be

withdrawn; these valves are all of one size, and flat, so that either side may be used, they are retained in position by the set screws C^1; A^1, the delivery air-vessel; the dotted circle T shows the suction inlet; X, the flange to which the double delivery-outlet with stop-valve is attached; V, the piston of water-cylinder with its double leather cap-packing to which access is obtained by the cover Z; YY screwed plugs at ends of water-cylinder.

The novel feature in this engine is the retention of the crank to terminate the stroke, combined with the absence of the fly-wheel; the crank D is moved over the dead centres by means of the piston M, of the auxiliary cylinder L, communicating motion by the piston-rod and small slotted cross-head G to the short crank F, which is in one piece with the main crank D, and at nearly right angles to it.

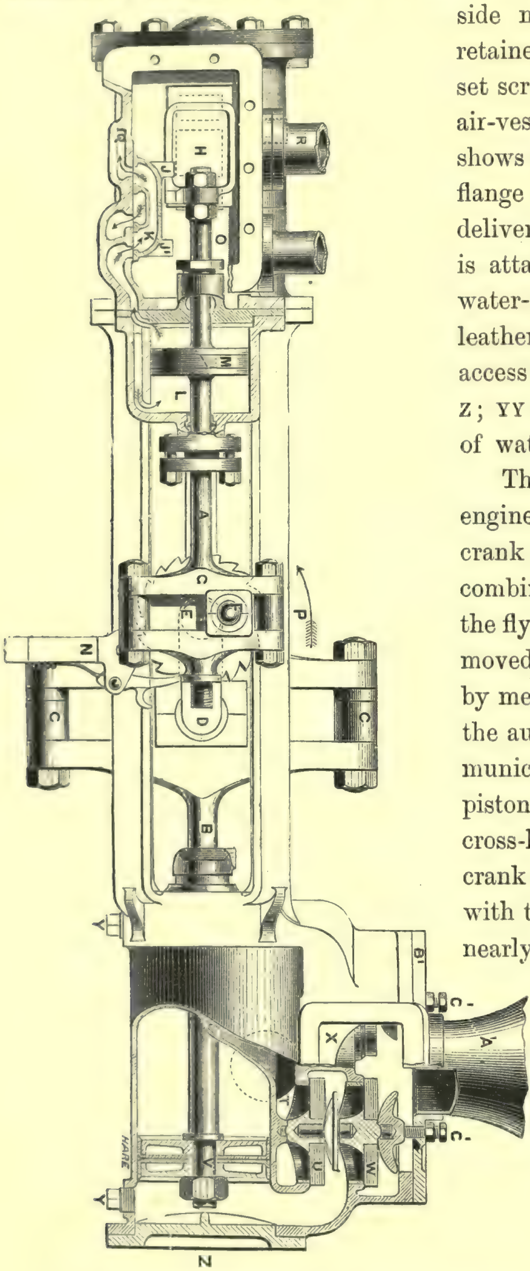

FIG. 42.—Section of the horizontal steam fire-engine, showing the arrangement of the force-pumps.

An engineer, stoker, and two firemen are required for working and applying a steam fire-engine. In travelling all ride on the hose-box except the stoker, who rides behind to attend to the fire. The period of

lighting the furnace is calculated from the time necessary to reach the scene of fire, bearing in mind the time that it is required to obtain steam of 100 lb. pressure. When arrived at the fire the engine is placed in a convenient position for working near the water, with the fore carriage moved round at right angles to give greater steadiness; the necessary lengths of suction-pipe are then connected together with the strainer at one end (entirely immersed in the water) and the engine at the other.

The importance of these applications for populous towns where the violence and extent of fires require prompt succour and efficient means of extinction requires no comment.

§ III.—Pneumatic Machines, or Gas or Air-Pumps.

Pneumatic machines are really air or gas-pumps, with the peculiarity that the fluid which they draw from a hermetically closed space and force to the exterior gradually diminishes in density without, however, bringing this density to zero, that is to say, without producing a perfect vacuum. Scientific experiments require air-pumps to be constructed with great exactness, in order that the exhaustion obtained should approach as near as possible to a vacuum. With the most perfect of these instruments the pressure of gas or air which remains at the end of the experiment in the receiver may be reduced to 0·1 millimetre. But it is not necessary to obain such a perfect vacuum in industrial applications, and it is then more advantageous to make use of an air-pump, invented and constructed by M. Deleuil, an ingenious maker of delicate instruments of precision. Plate III. gives a view of this machine, and in Fig. 43 the piston and barrel are drawn on a larger scale. It differs from ordinary air-pumps by the introduction of an interesting and original principle. The piston (instead of being lubricated with oil in order that a perfect contact between its surface and that of the pump-barrel may prevent all escape of air) in reality does not touch the pump-barrel at all; it is moreover furrowed with parallel and equi-distant grooves. The very small interval ($0^{mm}\cdot02$) which the constructor thus leaves between the two surfaces is filled with a thin

stratum of air. Now, experiment proves that the adherence of this gaseous pad to the surface of the piston is such, that it replaces the oily substance with which the piston is generally covered; in a word, its presence is sufficient to intercept all communication between the spaces of the pump-barrel above and below the piston. M. Deleuil at first gave to the latter a height double its diameter, and he obtained a vacuum from 8 to 18 millimetres according to the capacity. Since his first experiment, although he has given to the diameter of the piston a value equal only to its height, he has been able to obtain a vacuum of 2 to 3 millimetres in a capacity of 14 litres; in a quarter of an hour, he has obtained a vacuum of 10 millimetres in a receiver of 250 litres.

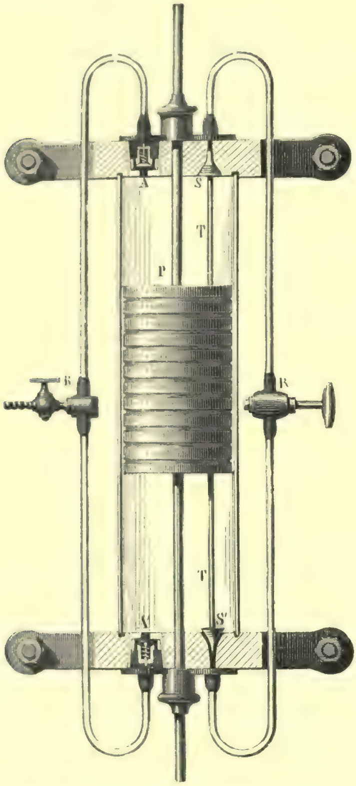

FIG. 43.—Piston of M. Deleuil's air-pump.

§ IV.—ATMOSPHERIC RAILWAYS.

One word now on the industrial application of air-pumps. One of the most important has been the use that has been made of them on some railways to obtain motion without the help of locomotives.

The principle of this application is very simple. Along the whole length of the railway a tube or metallic pipe is fixed, in the interior of which a piston can move. By the aid of an air-pump, a vacuum is made in the tube on one side of the piston, the atmospheric pressure being exerted on the other side on its surface; this causes the piston to which the train is attached to move.

The idea of making use of atmospheric pressure as motive-power

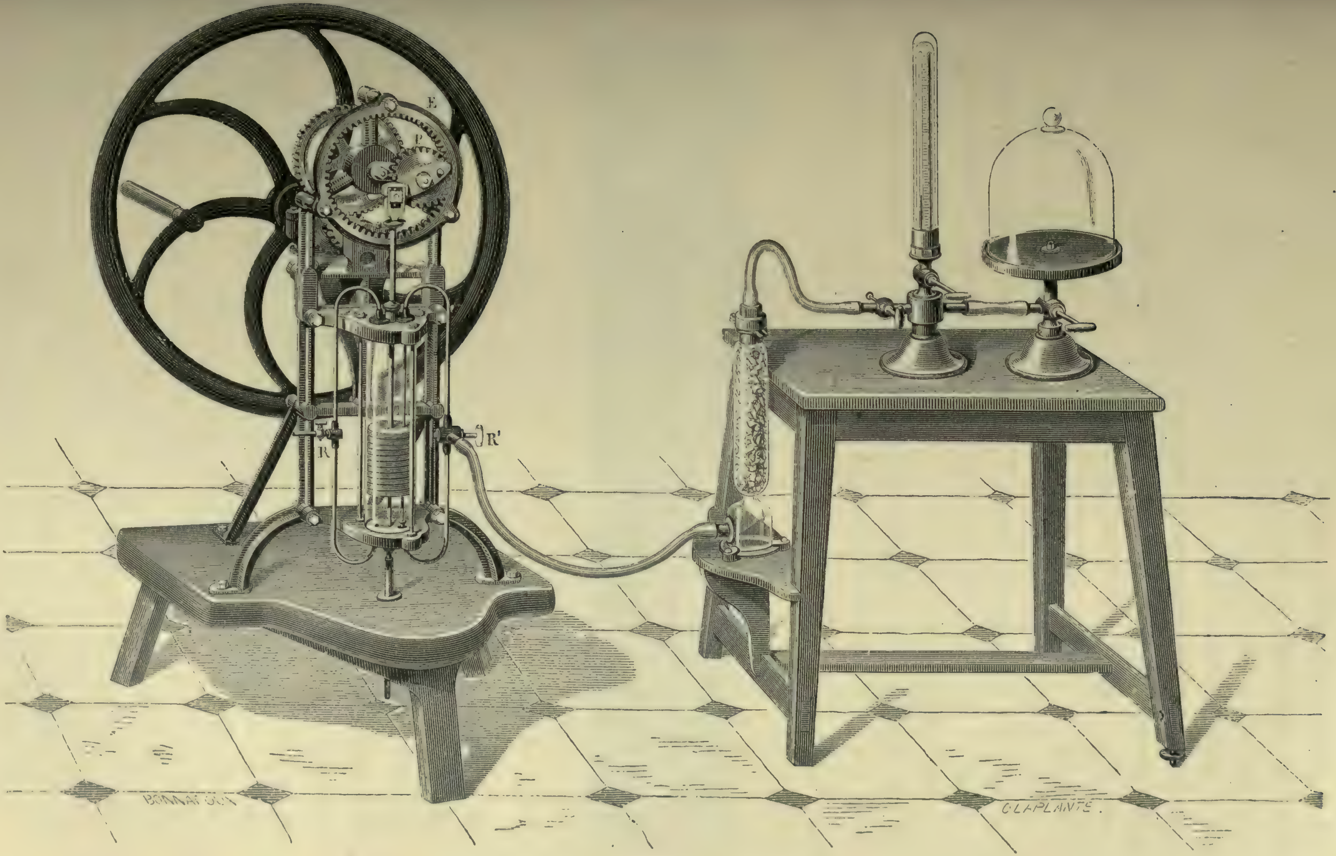

PLATE III.—DELEUIL'S AIR-PUMP.

is old; it goes back to the first experiments of the inventor of the air-pump, Otto von Guericke. In 1810, a Swedish engineer, Medhurst proposed to transport merchandise, parcels, and letters, in a tube in which a vacuum was made; then, to communicate the movement of the piston to carriages passing outside the tube. In 1824, an Englishman, Wallance, had the idea of transmitting atmospheric pressure directly to the carriages which must then travel in the interior of the tube where the vacuum is produced. The first atmospheric railway was constructed in 1848, in Ireland, nearly three kilometres in length, between Kingstown and Dalkey. The engineers Messrs. Clegg and Samuda again took up Medhurst's system, with improvements. Many other trials were made in England and in France, and on part of the Paris line to Saint-Germain. In the present day, all atmospheric railways have been

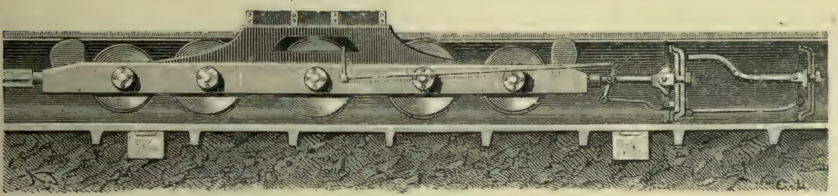

FIG. 44 —Pneumatic tube of the atmospheric railway of Saint-Germain.

abandoned, not that the mechanical working has proved bad, but because, in an economical point of view, this mode of traction has turned out inferior to that of locomotives; it was much too expensive. The invention of mountain-locomotives for ascending steep inclines has consequently forced the plan of which we have just spoken to be abandoned.

Fig. 44 represents a section of the tube (of sixty-three centimetres diameter) in the interior of which the piston travels, in the atmospheric railway of the Pecq at Saint-Germain. This tube, fixed in the centre of the railway, was pierced by a longitudinal slit through which the metal plate or rod fastening the piston to the first carriage passed. In front of the piston, that is, on the side of the vacuum, the slit was closed by a band of leather furnished with short iron plates acting as a valve, and a series of rollers of decreasing

diameters, carried by the framework of the piston, raised this valve in proportion as the plate joining the rod of the piston to the train advanced.

The vacuum was made in the tube by air-pumps, composed of four pump-barrels worked by a steam-engine. The dimensions of the tube and the machines were calculated so as to give a velocity of one kilometre per minute, supposing a train of fifty-four tons, with an exhaustion of one-third of an atmosphere.

CHAPTER IV.

INDUSTRIAL APPLICATIONS OF COMPRESSED AIR.

§ I.—The Air-Gun.

WE have just seen how atmospheric pressure may be utilized as a motive power. For that purpose it is sufficient to make a vacuum by means of air-pumps in the space through which the vehicle is to be moved; thus establishing a difference in the pressures exercised on the different sides of the moving body regarded as a piston. This difference of pressure can be obtained in another way; instead of rarefying the air in front, it can be compressed behind. The elastic power with which this air will be pressed against the walls will then be useful in different ways, and give rise to applications, to the most important of which we are now about to refer.

We noticed in the *Forces of Nature* the arrangements given to machines used to compress air or other gases. These are pumps which only differ from air-pumps in the working of the valves which are reversed.

The air-gun is one of the oldest applications of compressed air. The invention dates as far back as 1560, and it even appears that the ancients knew of a similar machine, as, according to Philon, Ctesibius made a tube out of which an arrow was sent by means of compressed air. However that may be, the air arquebus had been for some time in use in the army. In the present day it is only looked upon as a curiosity. The mechanism is as follows.

The butt-end of the gun is hollow and of metal; inside this is the reservoir in which the air is compressed by means of a force-pump. Formerly this was placed in the butt-end itself, and the reservoir

of compressed air was the circular space comprised between the barrel of the gun and a cylinder of much stronger make, which enveloped it. The butt communicates with the stock or part of the gun where the projectile rests, by an orifice furnished with a conical valve S, which the compressed air constantly keeps shut, but which may be opened by the working of the mechanism of the lock represented in detail in the figure.

By pressing the trigger *d*, the cock falls on the piece *e*, the lower part of which pushes a rod, *tt′*, communicating with the valve, which, with this sudden impulsion, suddenly opens. A portion of the compressed air escapes from the butt-end and projects the ball with a

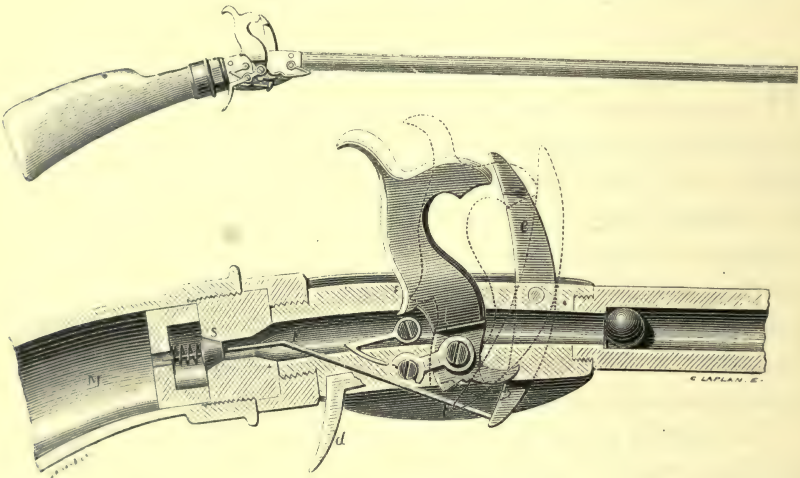

FIG. 45.—Air-gun: full view and section.

force which depends upon the pressure of the air by which the air-gun is charged. Generally this pressure amounts to 8 or 10 atmospheres. As only a small quantity of air escapes at each discharge, several successive shots can be discharged. In old air-guns the balls were placed in a little reservoir furnished with a stop-cock, and, as one shot was sent off, the stop-cock was opened and a fresh projectile placed in the stock. It is easily understood that the force of projection diminishes as the reservoir of compressed air is emptied, so that after a few discharges it is necessary to charge the gun afresh, that is to say, to compress the air.

The air-gun produces a noise, but much less than that of fire-arms of the same size, and a light is visible from the gun, which may be due to the ignition of the solid particles suddenly shot out by the aerial current; but, according to M. Daguin, this effect proceeds from the electricity developed by the friction of the wad and of the particles in question against the inner walls of the barrel.

§ II.—The Boring of Tunnels by Compressed Air.

In contemporary industrial works the power of compressed air has been and is still utilized in various ways. We will mention the most remarkable examples of this application.

In the first rank we must mention the boring of the immense tunnel which runs through the Alps, a little to the south of Mont Cenis, and joins the stations of Bardonnêche and Modane, the extreme stations, the one French and the other Italian, belonging to the Victor-Emmanuel line. In this there were 12,000 metres of archway to open through the rock, at depths which prevented the use of the ordinary process for boring tunnels, that is, by shafts sunk from above along the line of the intended tunnel.

The boring of this long tunnel could only be done from two opposite points: it appeared almost impossible to use steam and powder for excavating and for breaking down and crushing the rocks, because in proportion as the miners advanced further into the mountain the difficulties connected with the ventilation of the workings would increase, the air being vitiated by the mixture of the gases of the powder and steam, by the burning of fires and lamps, and by the carbonic acid given off by the workmen. The engineers[1] determined to adopt an idea which Colladon and, later on, Caligny had put forward—that of employing compressed air as the motive power of the machines to be used for boring the rock. The compression-pumps, or machines employed to compress the air in the reservoirs or receivers, themselves borrowing their power from a neighbouring fall of water (the stream from Melezet to Bardonnêche, and at Modane the little river of Arc). At the commencement, the air-compression pumps, thus called from

[1] MM. Sommeiller, Grandis and Grattoni.

the manner in which the water acted in three vertical tubes furnished

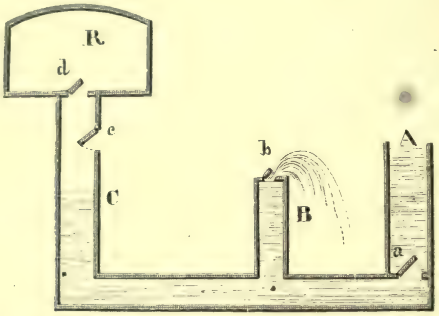

FIG. 46.—Hydraulic ram for compressing air.—Theoretical diagram.

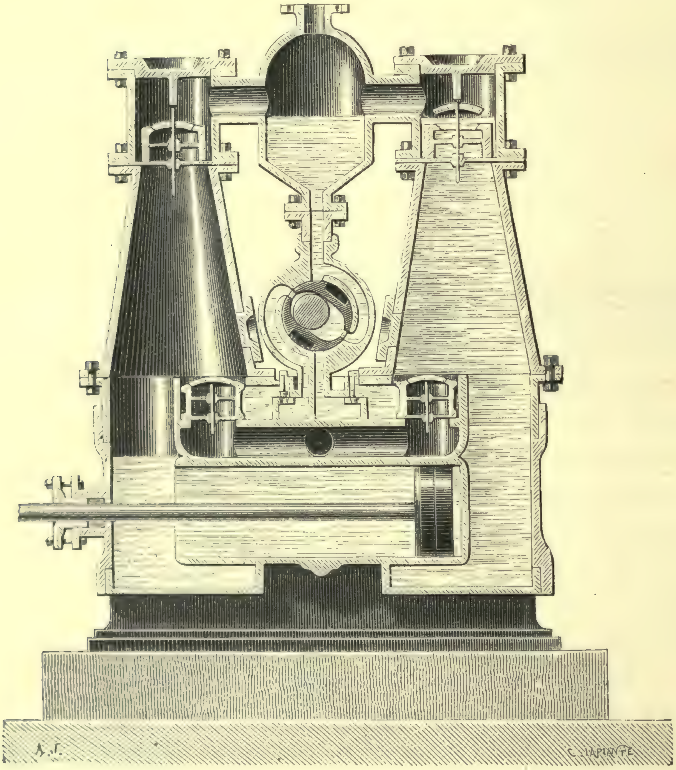

FIG. 47.—Double-action compression pump, Fryer's system (New York).

with valves for forcing the air into the receiver, were used. The water

from the fall came through the pipe A, the valve *a* of which was alternately opened and closed, whilst the valve *b* of the pipe B was itself closed and opened; a special little machine produced the working of these valves. Finding *a* opened and *c* shut, the water, with its acquired velocity, passed through the tube C, and, by rising, compressed the air brought from the outside by the valve *e*. This one was closed, whilst the air, more and more compressed, forced the valve *d* and introduced itself into the receiver R. Then the valve *b*, on being opened, whilst *a* was closed, the water escaped by the pipe B, *c* being opened and admitting a fresh quantity of exterior air, another arrangement compressed it and introduced it again into the receiver R.

Since then, engineers have substituted double-action compression-pumps for the hydraulic rams. They are of much more simple construction and require less power. The following are a few details of the way in which these machines were worked at Modane.

Twelve compression-pumps received their motion from six hydraulic wheels put in motion by the fall of the Arc. Each of them consists of a piston which receives backward and forward movement in a horizontal cylindrical body. At the two extremities of the cylinder are fixed two vertical tubes, each furnished with two valves: an admission valve, which is at the lower part of the conically formed tube, which admits the air from the exterior, and a valve introducing the compressed air by the ascending of the water and allowing it to penetrate into the corresponding reservoir.

The movement of the piston, by forcing the water into one of the cylinders, lowers its level in the other. The air is then compressed in the first and rarefied in the second.

Taking into account the losses occasioned by escapes, the twelve compression-pumps compressed in the mean, in twenty-four hours, 116,000 cubic metres of air at the ordinary pressure, and the pressure at which this air was supplied to the perforating machines attained 7 atmospheres.

Such a considerable quantity of air would not have been necessary, if the boring machines alone had had to be put in motion. In fact, the tube which conducted the compressed air from the compression reservoirs at the bottom of the gallery both supplied power for the perforating machines, and air for the workings of the whole tunnel.

A word now on the perforating machines. They were placed to the number of ten on a carriage free to move, forwards or backwards, on rails; a second vehicle, a kind of tender behind this, carried the reservoirs of water and compressed air (see Plate IV). The compressed air, introduced through a box in a cylinder furnished with a piston, communicated to the latter and to its rod the oscillating movement which, transmitted to the cutters, caused the repeated striking of the tools on the rock. But besides this longitudinal or clashing

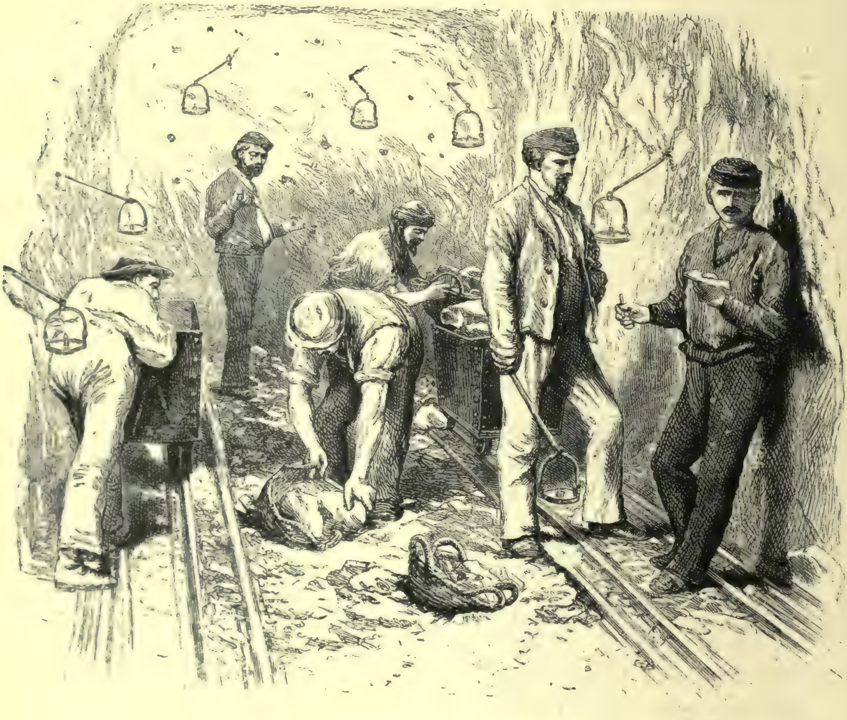

FIG 48.—Clearing the rubbish in the Alpine tunnel.

movement, each cutter possessed two other movements, indispensable in the nature of the work to be accomplished by each of them. In boring its hole, the cutter was obliged to turn gradually on itself like a gimlet, and also to advance as the hole became deeper. These two movements were produced by a small lateral machine moved like the other, by compressed air, and serving at the same time to regulate the movement of the slide valves of the first, to act on a rachet

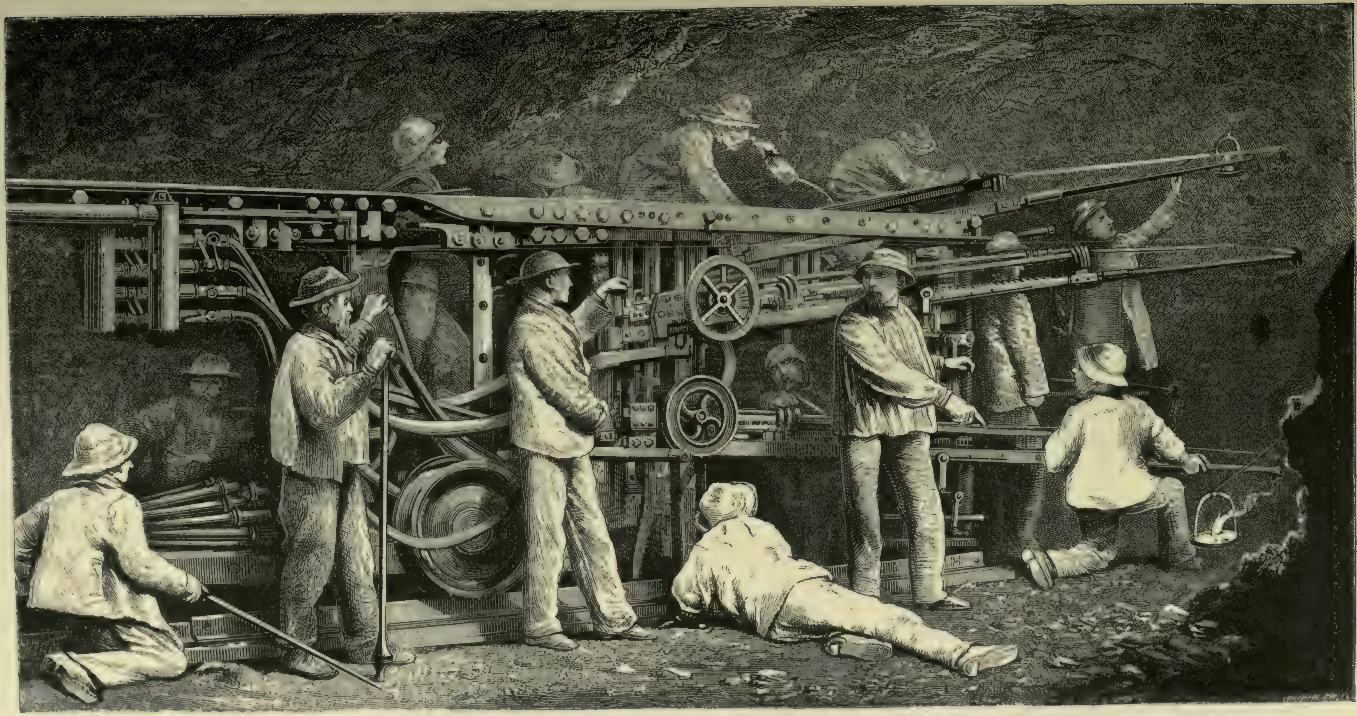

PLATE IV.—PERFORATING MACHINE OF THE MOUNT CENIS TUNNEL.

wheel which impelled the piston and the cutter, and to force forward the cylinder gradually as the boring of the hole of the rock advanced.

Each perforating machine could give 200 strokes of the cutter in a minute, consuming at each stroke a little less than a litre of compressed air. The rate of advance of the work. depended naturally partly on the nature and hardness of the rock.

The success of this application of compressed air as a motive power, in an enterprise which could only employ steam with difficulty, suggested the idea of extending the use of this power to other works; for instance, in countries where the water-courses produce falls, and consequently natural power, they could be employed to compress air, which could be distributed, through pipes, to the homes of a labouring population, and thus solve the problem of the economic distribution of power. In the meanwhile, while this use and transformation of the force of water-falls is being realized and comes into general use, it will be well to point out some of the special applications used in the present day.

§ III.—Compressed Air Posts—Compressed Air Railways.

A few years ago, the Administration of Telegraphic Lines established in Paris a communication between the two stations of the Grand Hotel and the Place de la Bourse. A tube 1,100 metres long and $0^{m}\cdot065$ in diameter connected at each of its extremities two chambers which served to introduce into it or to extract from it a piston carrying despatches. This piston, cylindrical in form, is nothing more than a box closed at one end and at the other furnished with a movable lid. The despatches are placed under cover in the interior. A covering of leather enables the piston to adapt itself exactly against the sides of the tube, in a way to prevent the passage of the compressed air.

Each chamber can by using two cocks be placed in communication at will either with the exterior free air, when the despatches are to be received, or with the reservoir of compressed air if the piston-carriage is to be sent to the other station.

As to the compression of the air, it is managed in a very simple and economical way, with the assistance of the pressure from the water from the town reservoirs, which at each of the two stations about

equals a fall of 15 metres in height. Three iron-plated troughs are for this purpose placed close to each station; one receives the water which compresses gradually as it fills up the trough the air situated above and forces it into the two others. By emptying the first cistern by means of a cock communicating with the outer air, then leaving it to fill again with water from the pipes, the same experiment can be repeated several times in succession, and the compressed air can thus be interned in the two other cisterns at the necessary pressure. Three minutes suffice to obtain this result, and the piston, driven along the tube by the force of the compressed air, reaches its destination in 90 seconds, which gives a mean velocity of 12 metres a second.

It is evident that all allowance being made for the expense of pipes and apparatus, the same system could be advantageously applied to the transport of letters and small parcels to every part of a city like London. There certainly would follow great economy of time in the expedition and distribution of such increasing and brisk correspondence.

In the United Kingdom, transmission of messages by means of pneumatic tubes is largely adopted, and in London, in connection with the General Post Office, a large system has been established.

The idea of using a pneumatic tube for message purposes emanated first from Mr. Latimer Clark, the engineer of the Electric and International Telegraph Company, who, in 1854, laid a tube from the Central Station to the Stock Exchange, and by means of a vacuum produced by a hand-pump the carriers were drawn through. Subsequently compressed air and steam power was used, so that carriers could be made to move in either direction; the advantages of this plan were so great that it rapidly extended, and at the present time most of the important provincial towns are provided with tubes, whilst in London alone there are twenty-five tubes, representing a length of nearly eighteen miles.

The system adopted in this country, where speed is so essential, is that of "radiation" from the Central Station. Tubes are laid direct to the different branch offices, and where the traffic is great two tubes are laid.

The tubes employed are of lead, 2¼ inches in diameter, and manufactured in as long lengths as possible—about 29 feet. The tubes are laid in iron pipes to protect them, and the joints are most

carefully made, so that whilst being perfectly air-tight, the surface of the tube is kept as smooth as any other part.

The tubes are all worked from one centre, where the engines and air-pumps are fixed: in London there are for the purpose of compressing and exhausting air, 3 engines, each of 50-horse-power (nominal). In the busy parts of the day, two engines are in use, whilst the third is kept spare. The air-pumps are six in number, and are of the diameter of 35 inches with a stroke of 3 feet. From the pumps lead two large mains, one for "pressure," and the other for "vacuum;" these mains reach to the instrument gallery. The size of the mains is so arranged that the intermittent action of the pumps is obviated.

The tubes are arranged in the gallery side by side,—first those for receiving only, then those for alternately sending and receiving, and

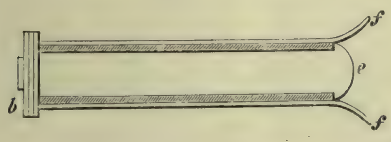

FIG. 49.—Section of carrier.

lastly those for sending only. The tubes terminate in valves, which are possessed of a double action, so that they can be used for sending or receiving, or for both; in connection with these valves are pipes which communicate with the mains.

Every carrier containing messages is signalled electrically, and its arrival is also made known in a similar manner: this is particularly necessary when an "up" and "down" traffic is carried through the same tube.

The carriers or pistons in which the messages are placed, are made of a cylindrical box of gutta-percha. A section is shown above.

The portion shaded is the gutta-percha, which is covered with felt or drugget projecting at the ends *f f*. The front of the carrier is provided with a buffer or piston *b*, just fitting the lead pipe. At the

open end is an elastic band *e*, which prevents the messages from falling out. When a carrier is placed in a tube and despatched, the air fills up the loose end at *f*, and makes it fit the pipe quite close.

The advantages of the pneumatic tube have been found so great, that a system has been introduced into the large instrument gallery for despatching messages from point to point for delivery and retransmission. It has been found to work admirably, not only economising time, but doing away with the constant rushing about of messengers.

In New York there has been constructed a short atmospheric railway, leading from Warren Street to the lowest end of the city near

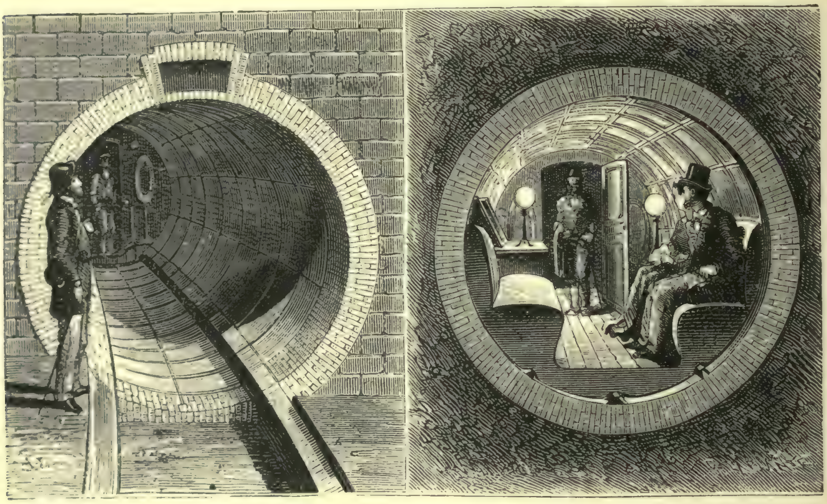

FIG. 50.—The New York atmospheric railway. FIG. 51.—The interior tube of a carriage.

the North River. The cylindrical tunnel has fixed on its lower part (Fig. 50) two rails on which a vehicle for travellers alone runs ; this is nearly of the same diameter as the tunnels through which it passes, and is forced along by the pressure of the air. Fig. 51 represents the interior of this carriage.

It will be seen, therefore, that these applications of atmospheric pressure as a motive power are more than interesting experiments ; their success in a small way is not difficult, but without improvements not yet realised, they do not appear susceptible of being put into practice on a large scale.

There is one of these railways carried under the Thames near the Tower.

It is only in very extensive and populous towns that an underground network of pneumatic tubes can be established with great advantage for the quick distribution of parcels and telegraphic or postal despatches.

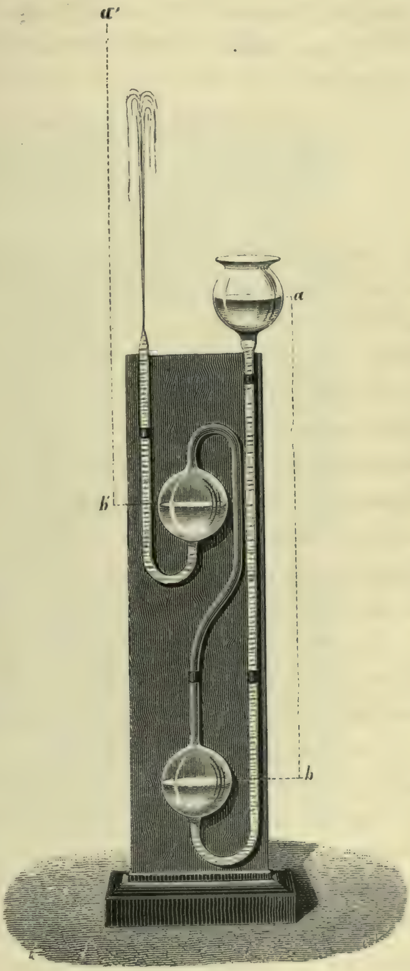

FIG. 52.—Nero's Fountain.

The pressure of water, used to compress air, produces a fountain on the surface of a reservoir in the ingenious apparatus known as Nero's fountain, so called from the name of a mathematician of the Alexandrian school, to whom the invention is attributed.

A reservoir of water A communicates by a tube which leads from the bottom with the outer air; it also communicates by a tube full of air with a reservoir C partly filled with water and surmounted by a column of water *a, b*. Upon the height of this column depends the pressure of the air inclosed and compressed between A and C. This pressure exerting itself at A on the surface of the liquid of the first reservoir, causes the water to rise in the tube, and if the height of this latter above the level of the surface of the water is less than the length *a, b*, the liquid will form a jet which theoretically would be exactly equal to their difference. It would rise to *a′*, if the line *a′, b′*, is taken equal to the height *a, b*; but the resistance to which the water is subjected in its movement in

the tube and that which the outer air opposes to it, necessarily reduces the height.

Nero's fountain is not a simple physical curiosity, and that is the reason we have mentioned it here. The arrangement has been reproduced and the principle applied in the construction of draining machines, such as the machines in the Schemnitz mines in Hungary, which are only gigantic Nero's fountains, constructed, it must be understood, with the solidity necessary to an application of this kind.

§ IV.—Use of Compressed Air in Bridge Building.

Compressed air has also received an application of another kind which is not less interesting than those to which we have just referred. It has been used to force the water from metal caissons, intended to form the foundations of the piers of bridges. We are indebted to M. Triger, a French engineer, for the first idea and application of the first method of this kind. Different processes have been used according to the circumstances and the views of engineers who have applied it; but as the physical principle is the same, it will be sufficient to describe one of them briefly in order to understand the others. Let us take the one adopted in the construction of the bridge of Kehl on the Rhine.

Figure 53 represents the arrangements made for laying one of these foundations, the interior of one of the caissons lowered below the bed of the river, and the workmen who are clearing it.

Let us imagine an enormous box, with sides solidly bolted and strengthened with girders and iron supports in the interior as well as on the upper side. This box, of rectangular form, is open at the bottom, whilst the roof, pierced with three circular holes, is surmounted by three chimneys in iron plate, the two lateral chimneys communicating simply with the interior of the box, and each surmounted with an air-chamber; that in the middle descends below the base of the box. Let us suppose this sort of diving-bell lowered to the bottom of the river, so that its open base rests on the bottom: the water will fill it, and, by virtue of the law of equilibrium of liquids in communicating vessels, it will ascend in the three chimneys to the level of the water of the river. If now, by using steam

condensing pumps, (these machines are seen in boats to the right of the drawing), air is forced into the two side chimneys, the increasing pressure of the air, greater than the exterior pressure of the atmosphere, will by degrees force out the water which fills the box, and cause it to escape by the open bottom, and will leave the bed of gravel on which it rests quite exposed, not to say dry. The middle chimney alone, which penetrates into the gravel, will

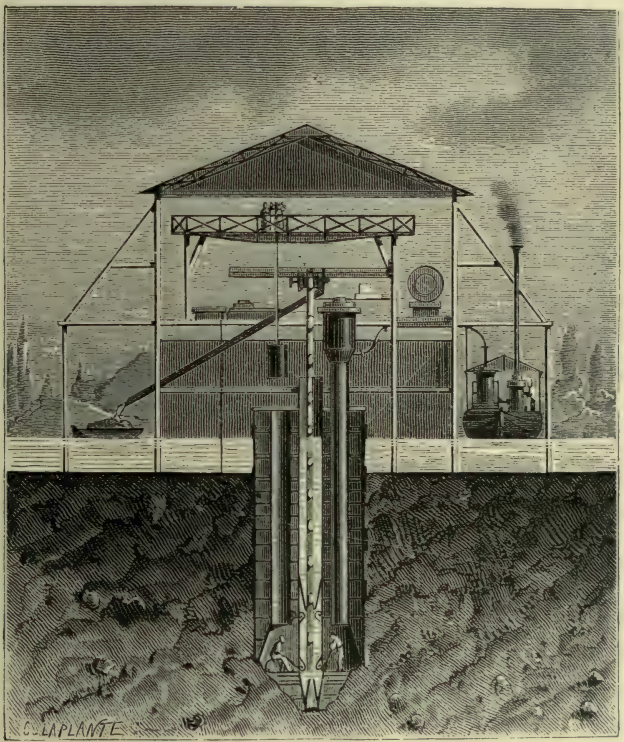

FIG. 53.—Foundation of the piers of the bridge of Kehl by the use of compressed air.

continue to be full of water. The workmen selected to make the foundations then descend, by the help of chambers forming locks in the lateral chimneys, into the interior of the box thus filled with compressed air. Protected by a pressure of 2 and 3 atmospheres, which guards them against the invasion of the water of the river, they dig out the soil and throw the rubbish towards the base of the central chimney.

A dredge, inclosed in this chimney, ascends with its buckets and

turns out the *débris* into the boat outside. While this goes on the stonework slowly built on the upper part of the caisson presses it down by its weight and forces it to descend until it arrives at the required depth. Then the workmen leave the caisson, the three chimneys are filled with cement, and the foundation is finished.

The bridge of Kehl is formed of two abutments and four piers: the two extreme piers each rest on four caissons; the two others, on three caissons only.

It must be added that work in chambers where the air is at such great pressure is not without danger to the health of the workmen.

§ V.—Measuring Heights by the Barometer.

The experiments made by Pascal in 1648 at the foot and at the top of the Puy de Dôme, and those also made by himself at the top and at the base of the tower of St. Jacques la Boucherie at Paris, were intended to determine whether the pressure of the atmospheric column of air was really the true cause of the rising of the mercury in Torricelli's tube. As the new theory came out victorious from the experiment, an important application of the barometer was realized.

It is evident, indeed, that a barometer may be used to measure heights, and that by noting the two different points to which the column of mercury rises at two stations of unequal altitudes, from the difference of the two levels, the difference of the two altitudes ought to be determined. This, of course, supposes that the relative densities of air and mercury are known, and that this density does either not vary at all, or varies in a determined ratio, in the thickness of the stratum which separates the two stations.

Let us imagine ourselves in a place where the temperature of the air is 0°, the barometric pressure 760 millimetres, which is near the mean pressure at the level of the sea in the south of England. In these conditions the mercury, with equal volumes, weighs 10,500 times more than the air. A barometric height of 1 millimetre of mercury is equivalent then to a column of air of 10,500 millimetres, or $10^{m.}$ 5, on the hypothesis that the successive strata of air do not vary in density or temperature. This, however, is not the case. The

very simple calculation, therefore, which would consist in deducing for each millimetre of difference in the barometric height a corresponding difference of $10^{m}\cdot5$, in altitude, is not applicable, or at least is only approximate for very small heights.

The strata of air, in fact, in proportion as we go higher, diminish in density, precisely because the pressures which they undergo are less and less considerable. Halley and Newton discovered the law of this variation, and showed that if the heights follow an arithmetical progression, the pressures vary in geometrical progression. Besides, the temperature starting from a certain height, diminishes progressively with the altitude, and from this there follows an increase of density which must also be taken into account. Lastly, the hygrometric state, or the quantity of vapour contained in the air has also an influence on the pressure.

The problem is therefore much more complex than it appeared at first, and the formula that Laplace has given is not so simple that we can describe it here. Let us only state that it is necessary to observe at the lower station and the higher one simultaneously; first, the height of the barometer; secondly, the temperature of the instrument itself, given by the thermometer fixed to it; thirdly, the temperature of the surrounding air, by the detached thermometer; and lastly, the temperature of evaporation by the wet bulb. The hour at which the observation is made should also be noted.

These four series of measures taken, it is possible to deduce the differences of altitude of the two stations. It is necessary as much as possible to avoid accidental variations, to make the observations of which we have just spoken. If the two stations are at some distance from each other, the observations should be made simultaneously, or if that is not possible, care must be taken to repeat them at the station at which they were begun, in order to ascertain how far during the interval the elements may have changed. In every case it is preferable to make the observations at different times and to calculate the required altitude each time. By taking the mean of the results, a closer approximation to a precise result will be obtained.

The formula supposes that the pressure and temperature vary with the height according to certain laws, which are approximately exact only for small differences of elevation in the atmosphere. When they are applied to determine the height of the atmosphere itself

the numbers are less than those deduced from astronomical observations, owing probably to our ignorance of the physical data at great heights, particularly of the true law of decrease of temperature with the height in the free atmosphere. For instance, only 57 kilometres are found for the height of the stratum in which the pressure is not more than the tenth of a millimetre.

CHAPTER V.

BALLOONS—AERIAL NAVIGATION.

§ I.—APPLICATION OF THE PRINCIPLE OF ARCHIMEDES TO THE VERTICAL ASCENSION OF BODIES IN THE ATMOSPHERE.

A BODY immersed in a fluid loses in weight a weight equal to that of the fluid which it displaces. This principle, which is known to have been discovered by Archimedes, applies to gases as well as to liquids, and hence it is that many light bodies—smoke, vapour, and clouds—rise and remain suspended in the air, instead of falling to the surface of the earth as would happen on a planet devoid of a gaseous envelope or atmosphere.

In order to bring about this ascent, it is necessary that the weight of the body be less than that of the portion of air which it displaces. At the surface of the earth, the air weighs 1·29 at the temperature of 0° and under a pressure of $0^{m}\cdot76$, that is to say, the weight of a cubic metre of air is then $1^{kil}\cdot29$. Under the same physical circumstances, a cubic metre of hydrogen gas has a density about fifteen times less, as it only weighs $0^{kil}\,090$. Let us imagine such a volume inclosed in an impermeable envelope; the loss of weight which it will undergo in the air will be $1^{kil}\cdot29$, and as the weight of the gas is only $0^{kil}\cdot09$, it will be raised in the vertical direction with a power equal to the difference of these weights. Part of this buoyancy or ascending power will be used to balance the weight of the solid envelope, and the remainder will serve to raise the system to a certain height in the atmosphere. As the strata of this latter have a density which decreases with height, the ascending power will go on diminishing gradually until it entirely ceases. At this point, the balloon will cease to rise, and if its movement continues it will

be due to ascending aerial currents in the region of the atmosphere in which it finds itself. Such is briefly the theory of aerostation, which was only understood and successfully applied for the first time in 1783 by Joseph Montgolfier. In reality, the idea of rising and being suspended in the air had a long time previously suggested numerous projects more or less chimerical which mostly existed in the imagination of their authors; the rare attempts at realization and execution were frustrated on account of insufficient knowledge of mechanical and physical laws.

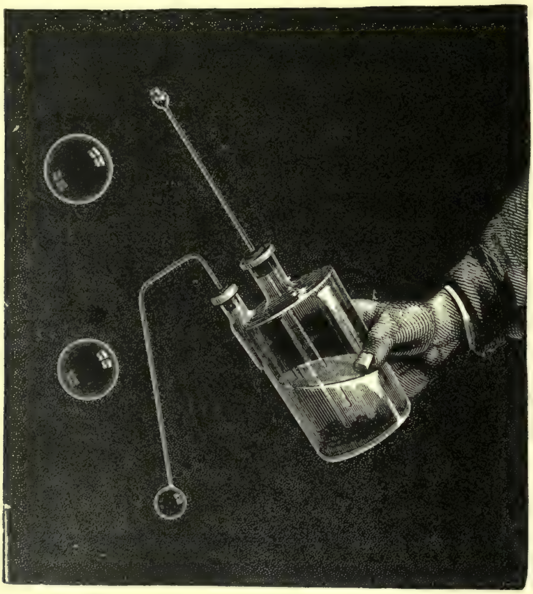

FIG. 54.—Ascension of soap-bubbles filled with hydrogen.

Joseph Montgolfier, who doubtless knew of the experiments of Black, Cavendish and Cavallo, on the ascension of bladders and soap-bubbles filled with hydrogen gas (Fig. 54), formed the idea of imitating these experiments on a large scale, and of making them of use in the exploration of the atmosphere. He first made balloons of silk or paper, which, filled with hydrogen, rose to a certain height, but descended very soon, as he foresaw, because the gas escaped through the permeable envelope. He then substituted warm air for the hydrogen, the density being much greater than that of the gas,

but less than that of the cold air, and its production easier and less expensive. On the 5th of June, 1783, Montgolfier's first experiment on a large scale took place, at Annonay, before the States of the Vivarais, accompanied by an immense crowd. A balloon with an opening at its lower end through which the air warmed by a brazier supported by a wire basket ascended into the balloon, rose to a vertical height of two kilometres (6,560 ft.) amid the enthusiastic plaudits of a multitude of spectators.

The experiment of Annonay, which was considerably applauded, was in less than three months afterwards reproduced in Paris under different conditions. The physicist, Charles, who shared the general ignorance in which Montgolfier had left the public with regard to the nature of the gas which filled his balloon, had the idea also of using hydrogen. He took for the construction of the envelope silk rendered impermeable by a coating composed of indiarubber dissolved in boiling spirit of turpentine. The hydrogen was obtained by the reaction of sulphuric acid on iron; it took several days to produce the quantity of gas necessary for the filling of the balloon. At last on the 27th of August, 1783, the Globe (the name of the first hydrogen-balloon) ascended from the Champ de Mars in presence of an immense crowd, and, after travelling three-quarters of an hour, descended at Gonesse in the suburbs of Paris. At the first bound, it was carried to a vertical height of 1,000 metres; then, hidden by a cloud, it disappeared, and reappeared in a clear space at a much greater height, and then was again hidden in the clouds.

This is not the place to give the history of balloon-ascents, which were repeated frequently towards the end of the last century and in our own; but we have described these two first experiments, not only on account of the stir they made and the enthusiasm they evoked, but because they pointed out two different modes of ascension and two systems of balloons, which were called at the time fire and air balloons respectively.

This brilliant application of hydrostatic principles and of new physical and chemical discoveries received almost at one bound a great development, while at the present day we are far from having made the most of the means the discovery has placed at our disposal.

In the first experiments of Montgolfier and Charles, they were contented with the ascent of the balloons themselves; the idea of

using them to carry travellers and to explore the atmosphere followed afterwards. Indeed, the first aerial voyage took place the same year, 1783. On the 21st of November, a young naturalist and physicist, Pilâtre de Rozier, accompanied by the Marquis d'Arlandes, after a few trial ascents in a captive balloon, raised themselves in a fire balloon to a height of about a kilometre, and descended safe and sound at two leagues from their starting-point, having travelled over Paris. After this first and victorious trial of the conquest of the aerial regions, the ascents and voyages were repeated, not without some terrible catas-

FIG. 55.—Pilâtre de Rozier and Arlandes' first aerostatic ascent, October 21, 1783.

trophes, amongst which must be mentioned that of the unfortunate and bold Pilâtre de Rozier, who was thrown out trying to cross the straits from France to England, in imitation of the aerostatic passage of the Channel accomplished by Blanchard and Jeffries in January, 1785

We will say a few words presently on the ascents which have been undertaken for the purpose of the scientific exploration of the air; but first we will enter into some details on the construction and filling of balloons, as well as on the different arrangements used by aeronauts in their excursions.

§ II.—Montgolfières, or Hot-air Balloons, and Gas-Balloons —Construction and Filling.

Balloons, whether filled with hot air or gas, are generally of a nearly spherical form terminated at the lower part by a cylindrical or conical appendage. There is always this difference, that in the air-balloon this appendage, called the neck of the balloon, has an opening, whilst in the gas-balloon it is closed. This form is moreover that which the envelope would naturally take under the pressure of the elastic gas which it incloses, if it were equally extensible in all its parts. When in the air the orifice in the neck of the gas-balloon is always open, as in Fig. 56; it is only closed during inflation, to prevent the escape of the gas. The only difference between the air and gas-balloon is, that in the former the orifice is very large, as the stove chimney has to go up through it and be well separated from the material of the balloon, and in the latter the orifice does not exceed a foot in diameter.

The envelope is formed of spindle-shaped pieces of silk, which are sewn together, as it were along the meridians of a sphere; it is important that no fissure is left, not even the holes made by the pricks of the needle, and that the stuff itself should be of a close texture and if possible impermeable, to avoid escape of gas, which would diminish the ascending power. Montgolfier used in his first experiment a cloth lined with paper, sewn on a network of string, and fastened to it; in his second experiment, the envelope was of packing cloth, lined inside and outside with very strong paper. We have seen that Charles's balloon was of silk and covered with a varnish of indiarubber. The balloon that MM. Barral and Bixio used for their two explorations in 1850, was rendered impermeable by a coating of linseed oil thickened with litharge. Lastly, another good way of construction consists in placing a sheet of indiarubber between two sheets of silk.

The upper part of a balloon is covered with a net which hangs loose a little below its equator; all the cords of this net are brought down to a circle of very hard wood which serves to suspend the car.

Thanks to this arrangement, the weight is evenly spread on the

whole surface of the balloon covered with the net, and gives both to the car and to the travellers a steadiness absolutely indispensable.

To inflate a hot-air balloon, it is simply necessary to place a stove or vessel filled with burning materials under the opening; the

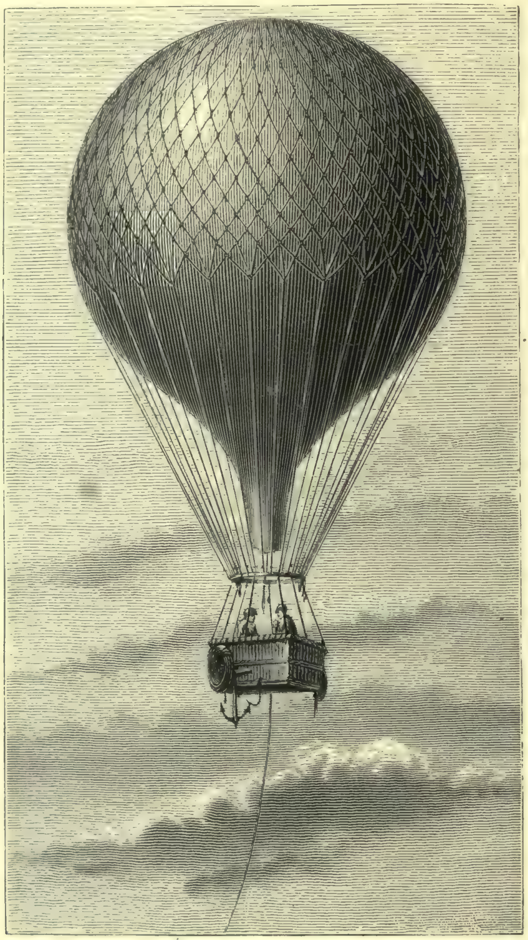

FIG. 56.—Gas-balloon.

heated air rises into the envelope, and by degrees its elastic force stretches the sides and makes them take a spheroidal form. When Montgolfier made his first experiments, he believed that electricity took part in the phenomenon of ascension, whilst it was the specific

lightness alone of the hot air which, by virtue of the principle of Archimedes, was the real cause. He also favoured the production of the fluid by burning straw cut up with damp wool, and believed that the straw and wool gave off a special gas to which the ascending power was due. De Saussure had no trouble to prove that the air produced had no other virtue than warm air, and that electricity went for nothing.

Balloons filled with hydrogen, although more expensive than hot-air balloons, are generally preferred. The necessity of carrying combustible materials, the danger of fire, and above all the inferiority

FIG. 57.—Car of the balloon *Le Pole nord.*

of the ascending power (much less with equality of volumes), are reasons for this preference.[1]

[1] The weight of a cubic metre under a pressure of 760 millimetres, is

1,293 grammes at	0°
1,247 grammes at	10°
945 grammes at	50°
278 grammes at	100°

Thus the ascending power of hot air, 46 grammes only per cubic metre at 10°, 348 grammes at 50°, rises to 1015 grammes at 100°. At 0° pure hydrogen is 1,203 grammes, at 10° it is still 1,160 grammes. As it is difficult to preserve the temperature of the air of a montgolfière at such a height, it follows that the ascending power is very much less than that of a balloon filled with pure hydrogen.

Nevertheless the construction of hot-air balloons has been much improved by substituting sponges soaked in spirit for the inconvenient combustibles of straw and wool. An aeronaut, M. E. Godard, has adapted to the fire a chimney surmounted by a metal curtain or screen, which guards against the danger of conflagration. The use of petroleum lamps would perhaps enable one to increase or moderate the temperature, and consequently, to rise or descend at will. M. Joseph Silbermann has made some interesting researches on this subject; his system of fire-balloons certainly deserves to be tried.[1] The inflation of balloons with pure hydrogen gas is accomplished in

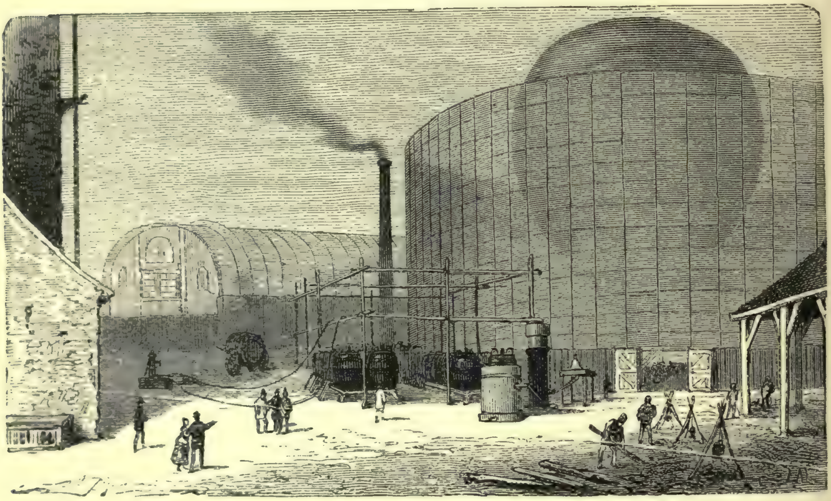

FIG. 58.—Operation of inflating a balloon with hydrogen gas.

the following manner. The gas is produced by the reaction of sulphuric acid on water, iron or zinc.[2] A system of casks inclosing these substances is arranged so that the gas is collected as it is formed, from a bell-jar reversed in a water trough, similar to a gasometer. Then after having been purified by its passage through

[1] In 1874 some experiments were made at Woolwich Arsenal with a balloon invented by Messrs. Menier and Simmonds, which was inflated by means of petroleum.

[2] In 1850 MM. Barral and Bixio used the reaction of hydrochloric acid on water and iron. The gas must be carefully washed to prevent the action of the acid on the envelope.

water, the gas is introduced by a tube into the lower part of the envelope, and by degrees the balloon is filled by the action of the elastic force of the gas.

In place of pure hydrogen, ordinary lighting gas, that is, carburetted hydrogen, is most frequently used. The density of this is much greater it is true, as it is as high as 0·63 that of air;[1] the ascending power is therefore then much less. But the advantage of easily obtaining a considerable quantity of gas in towns renders its use in every respect more advantageous. An English aeronaut, Green, was the first person to substitute ordinary coal gas for hydrogen; he first inflated a balloon with coal gas. Mr. Glaisher recommends for the same reason the use of gas obtained towards the end of the distilling operations. Thus, in his ascent of June 30, 1862, he obtained a gas with a density as low as 0·36, and which, therefore, gave an ascending power of 830 grammes per cubic metre, about two-thirds of that of pure hydrogen.

We may now state briefly by what means and by what management the aeronaut ascends and descends at will. We will not speak here of the direction of the balloons, as all movement in a horizontal direction depends only on the aerial current, which draws the balloon along with a velocity nearly equal to that of the mass of air itself. The direction of balloons is entirely denied, at the present time at least, to the aeronaut; his interference is confined to ascending or descending vertically, until he meets with a stratum of air moving in the direction he wishes to follow.

If the aeronaut travels in a hot-air balloon, by increasing the fire and thus increasing the temperature of the air inclosed in the invelope, he diminishes its density and consequently increases the ascending power of the apparatus. By lessening the fire, or allowing it to go out, the contrary effect is produced, and the apparatus begins to descend. In gas-balloons the means are no longer the same. To ascend, the aeronaut can only increase the ascending power at the expense of the contents of the car; he is obliged to throw out ballast, which most frequently consists of sacks filled with sand, and which one of the travellers empties in such a manner as not to endanger persons who might be underneath the balloon: it is always very fine sand which

[1] At 0° and 760 millimetres pressure, the ascending power of common gas is 693 grammes per cubic metre; it is 670 grammes at 10°.

could not hurt anyone. Ballast is nevertheless a very limited resource, which is exhausted rapidly; in many ascents the necessity of diminishing the rapidity of descent or fall has been accomplished by throwing over the sides of the car any heavy bodies—clothing, provisions, instruments, &c.

In order to descend, a certain quantity of gas is allowed to escape. The envelope partly emptied, the volume of the balloon diminishes and the air displaced becoming less, the globe descends until it finds itself in a stratum of greater density, which compensates for the loss of ascending power.

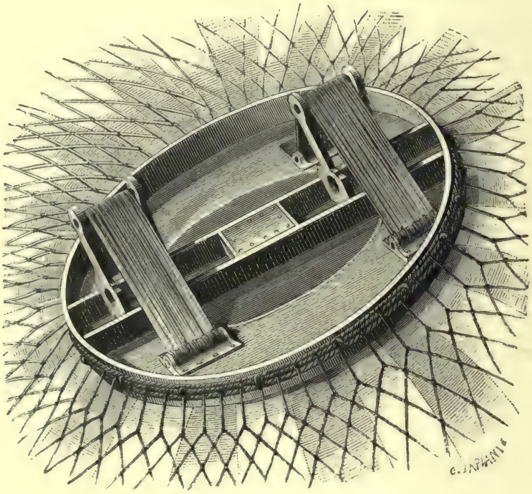

FIG. 59.—Valve of the balloon *Entreprenant.*

To render the escape of gas more easy and more regular, the balloon has at the top an opening which holds a valve, fixed in by springs. A string, which passes through the balloon and out at the neck, within reach of the aeronaut, enables him to open this at pleasure.

It is necessary to moderate the descent, without which the fall would become dangerous, as the velocity goes on increasing. "If we descended at one bound from a great height," said M. Barral, "the velocity that would be acquired on reaching the ground would be frightful, and the aeronaut would be destroyed by the fall. Hence the descent is accomplished in 'cascades,' that is to say, first a distance

of 500 metres; then, throwing out ballast, they again rise 100; then afterwards another descent of 500^{m}, then another rise, and so on, until the earth is reached, which an experienced aeronaut can do with the greatest precision, and without any accident whatever."

When the descent is final, and for some reason or other the journey is ended, the aeronaut, wishing to reach the ground, sometimes uses a

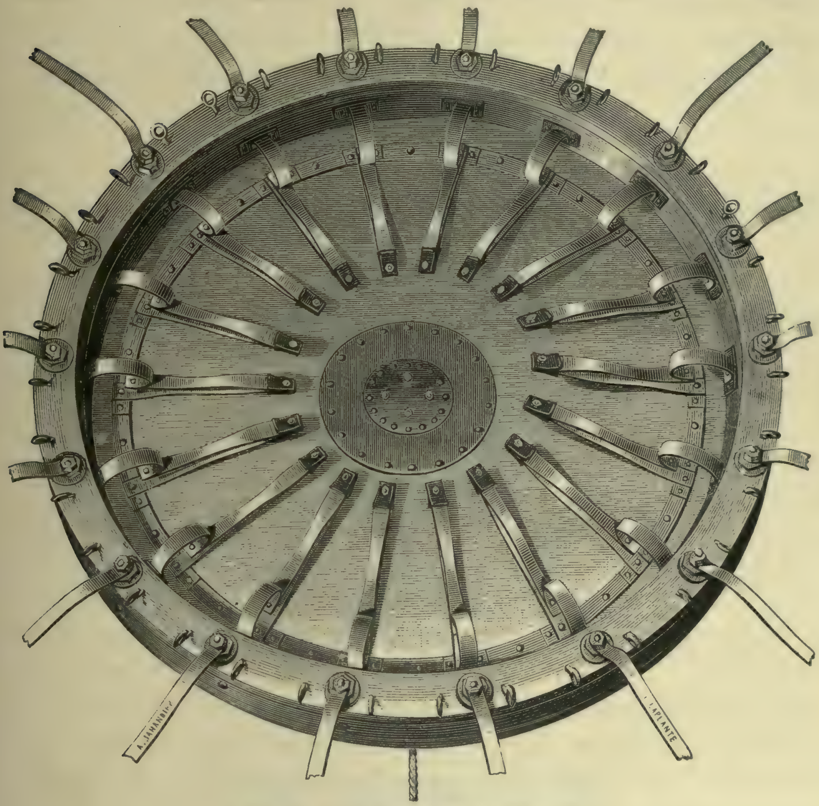

FIG. 60.—Valve of the balloon *le Pôle nord.*

cord (guide-rope) furnished with knots, which falls below the car and is fifty metres in length; by degrees, as a greater quantity of this new kind of ballast touches the ground, the weight carried by the car is diminished, which gives it a tendency to rise again. The rapidity of its fall is thus reduced. Lastly, one or two anchors may be used to hook on to projections on the earth, trees, bushes, rocks, &c., and to stop the balloon finally in its course. The utility of these various

instruments, and the efficacy of their working, depend especially on the skill and experience of the aeronaut.

A short time after the invention of balloons, the idea was conceived of using, in case of accident, a special apparatus, known as a parachute; this had been thought of a long time before. It is a kind of dome, formed of spindle-shaped pieces of stuff sewn together, which folds up and opens like an umbrella. Suspended either at the lower

FIG. 61.—A balloon fitted with its parachute.

part of the balloon or near its equator, it is attached to the car by a system of cords, arranged so as to carry this with its cargo as soon as the rope is cut by which it is suspended. The parachute at first is precipitated with increasing velocity, but the resistance of the air gradually and completely unfolds its surface, and the whole system can then descend gently to the ground. The parachute is very little

used. The aeronaut Garnerin was the first (1802) who dared to trust to an apparatus of this kind : he descended from a height of 1,000 metres ; but as no one had yet thought of making an opening at the top of the parachute to allow the escape of the air, he experienced several severe shocks, owing to the masses of air which escaped laterally, sometimes on one side and sometimes on the other. Unless in very bad accidents, or considerable rents in the balloon, aeronauts agree that the management of the descent of the aerostat itself is as safe as that of the parachute, which, in the majority of ascents, would be only an incumbrance and useless weight.

§ III.—Application of Aerostation to Military Purposes, to the Study of Meteorology and Terrestrial Physics.

It now remains for us to point out rapidly the uses aerostation can be put to and the services it has already rendered. In 1794, the Committee of Public Safety decided on the formation of companies of aeronauts or aerostiers, their work being to observe, by the help of captive balloons, the movements and positions of hostile armies. This new kind of spy was first turned to account at the battle of Fleurus ; in 1815, Carnot used it at the defence of Antwerp ; lastly, in the great War of Secession, military aerostation was restored with honour by the United States Government. A system of electric telegraphy enabled the Federal army to communicate with the aeronaut.

During the last Franco-German war balloons played a certain part, but they were not, properly speaking, used for military purposes. Paris, invested, and deprived of all direct communication with the rest of France, was able to send its despatches, correspondence, and a number of men charged with military or political missions, by the help of balloons, which were sent up when a favourable wind blew towards the parts not occupied by their enemies.

Fifty-four balloons, carrying 2,500,000 letters, representing a total weight of nearly 10 tons, were thus sent by the Government of National Defence, and carried out of Paris news from the great besieged town and the assurance of the heroic resolution which it had formed to resist till the last extremity. Unfortunately, the return

of these aerial messengers could not be effected, the route followed by them being at the will of the wind. The balloons had a chance of three to one of coming to a friendly country, and, owing to this fact, the greater number succeeded; only a few fell into the Prussian lines. One of them, la Ville d'Orléans, came down in Norway; two or three, indeed, were lost, probably in the sea. In the provinces, several attempts were made to direct some aerostats towards Paris, but they did not succeed.

The only efficient means for the return of the correspondences was the organization of the carrier-pigeon post; further on we shall have

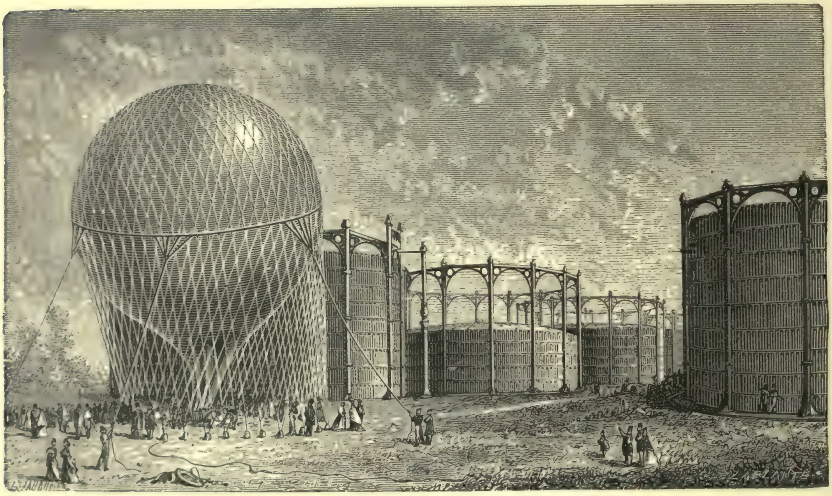

FIG. 62.--Departure of a balloon from the works of la Villette.

occasion to say a few words about it when we speak of microscopic photography.

As to the question of directing balloons, or to the more general problems of aerial navigation, a question and problems much talked about for the last twenty years, we have before stated that we shall not refer to them here, for the simple reason that no real practical solution has ever been proposed, or at least experimented on. However, we will mention a few interesting trials.

Among the experimenters there are some who have abandoned, for reasons which appear plausible, the idea of guiding at will machines

on which aerial currents have great hold. Besides the difficulty of loading the car of a balloon with the weight of a motor sufficient to drive a mechanism either with paddle-wheels or screw, there is the danger of fire, if this motor is furnished with a steam generator and consequently with a fire: hydrogen gas is, under these circumstances, too dangerous. Taking then their model in the ascending motive power of birds, these experimenters turned their efforts towards the discovery of a contrivance to raise and move machines heavier than air, thus reducing the resistance which aerial currents oppose to a large surface, and at the same time to avoid all danger of explosion and fire. Theoretically speaking, the solution of the problem is possible : the difficulty is in the practical realization.

On the other hand, instead of trying to find the complete solution of the direction of balloons, some savants, amongst whom we must mention first a French engineer, M. Giffard, have confined themselves only to obtain a sensible effect of deviation from the line of wind. This effect obtained, they have only to tack about, as seamen do, to cause the balloon to take the course nearest to the desired direction. Several trials were made by M. Giffard which did not give satisfactory results. They were repeated, twenty years later, in January 1872, by M. Dupuy de Lôme, who constructed an aerostat, having calculated the form, arrangement, and mechanism to the end we have just defined.

M. Dupuy de Lôme's balloon has an oval or oblong form, offering an axis with least resistance in the direction of motion. The propelling power is obtained by the movement of a screw with two or four branches, with taffetas or silken stuff sails, worked by a number of men, alternately replacing each other. The balloon is filled with ordinary gas. In its interior it carries a small balloon with a volume equal to the tenth of the volume of the large balloon and which can be filled with air by means of a ventilator carried and worked in the car. The purpose of this little balloon is to preserve a permanent form to the large one, whatever the variation of atmospheric pressure may be : it thus allows a descent from a height of 866 metres, when the dimensions are those of the machine made by the inventor, that is, with a total volume of 3,454 cubic metres for the large balloon, and consequently $345^{m}\cdot4$, for the small interior one. A rudder, formed by a triangular sail placed under the balloon, at the

back, serves to guide the machine in the desired direction, and to change this direction at will.

An experiment was made on the 2nd of February, 1872. The results appeared satisfactory, inasmuch as the aerostat, in spite of a tolerably strong wind, received a velocity from the screw equal to about 10 kilometres and a quarter (about 6 miles 440 yards) per hour. With this velocity, the balloon was able to deviate, when the screw was put into motion, from 10° to 12° from the course followed when the screw was stopped, that is to say, when the balloon floated along under the influence of the wind alone. These results, although not so brilliant as those which have been announced by many inventors of the direction of aerostats, constitute a real and steady progress which cannot but serve as a starting-point to subsequent improvement.

This is probably all which we can reasonably hope for in the present state of physical and mechanical research. The substitution of a powerful movement such as the steam-engine, to the muscular force of man, is the principal desideratum of the problem of aerial navigation with hydrogen balloons. The whole question would be to protect it from the inflammability of the gas.

A word now on the application of aerostation to the study of meteorology. Captive balloons would be able to furnish to this science statements of the highest importance. By placing at different heights a certain number of these machines furnished with registering instruments, data would be obtained which could only be had for a very short interval of time by aeronautic voyages.

Gay-Lussac and Biot, during an ascent they made together on the 24th of August, 1804, reached a height of 4,000 metres, and procured a series of experiments on the oscillations of the magnetic needle, in order to determine the variations of the magnetic intensity with altitude. The first of these savants made an ascent alone, which carried him to about 7 kilometres (23,000 feet) in vertical height. He was able to recognise that the composition of the atmosphere at this altitude was chemically the same as on the surface of the earth.

The illustrious physicist, who at the moment of starting read a temperature of + 27°·75 centigrade, found at the greatest elevation a temperature of − 9°·5; more than 37° difference.

Among contemporary scientific ascents we must mention those of

MM. Barral and Bixio in 1850, and the thirty ascents which Mr. Glaisher made from 1860 to 1865. Among the most curious results of the second ascent of the two first savants, we will quote the following: they discovered the existence, in the height of summer, of clouds entirely formed of icicles, of a thickness of 4 kilometres (13,480 feet); reaching the height of $7^{kil.}\cdot49$ (24,600 feet), where MM. Barral and

FIG. 63.—Mr. Glaisher's car ready for a scientific expedition.

Bixio found a temperature of 39° Fahr. below zero, nearly that of the freezing point of mercury.

Mr. Glaisher's journeys, together with those of the young and courageous French aeronauts, MM. de Fonvielle, Flammarion, and Tissandier, made one or two years ago, are described in detail in an interesting work, *Travels in the Air*, edited by Mr. Glaisher himself, to which we refer the reader who is curious to be initiated into the conditions of this kind of locomotion.

BOOK II.

ACOUSTICS—APPLICATIONS OF THE PHENOMENA AND LAWS OF SOUND.

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CHAPTER I.

SOUND-SIGNALS.

§ I.—Acoustic Signals in Navigation—Bell-Buoys—Speaking-Tubes—the Invisible Woman.

THE idea of using sound—the human voice, bells or other similar instruments—to communicate at a distance is of very ancient origin. The range of sound is doubtless infinitely less than that of light, and light signals furnished a means of distant signalling long before electricity brought this valuable and useful art to perfection. But light is not visible or is only faintly seen during foggy weather, or in the midst of storms: then sound is a useful auxiliary which is employed at the entrance of ports or in the vicinity of rocks. "In foggy weather," says M. Renard, "ports are signalled by bells rung at certain intervals. Some light-houses are furnished with this apparatus. In the United States [and at some places on our own coasts] where fogs are frequent and very thick, notwithstanding the expense a wide range of sound necessitates, at several points there are placed bells, weighing as much as or more than 500 kilogrammes, and at others, whistles, fog-horns, or syrens, worked by steam or compressed air." In narrow channels, near banks or rocks, buoys furnished with bells to warn mariners of danger, are often employed. Church bells, in country and in

towns are telephonic signals which give notice to people at a distance of ceremonies and divine service, and many persons recognize, on hearing the different styles of ringing, what is the nature of the ceremony announced. In case of fire, the tocsin sends forth its sinister sounds, and calls afar for everyone to help. But, in these cases the sound is employed in the open air, without any special process for sending it to a distance by preserving its first intensity. The means invented to conduct sound to much greater distances than its ordinary range, constitutes what is called telephony.

One method much used for short distances consists in causing the sound to be propagated in tubes, in which the mass of air set in motion at one extremity, transmits the full power of the disturbance.

Speaking-tubes are in the present day very frequently used in

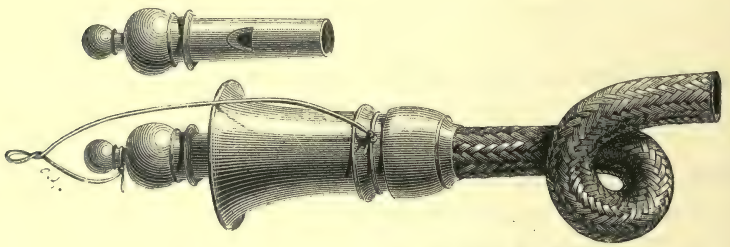


FIG. 64.—Speaking-tube, mouth-piece, and whistle.

private houses and commercial establishments, where the *employés* frequently require to communicate from one distant point to another, or from floor to floor. They are used also in vessels for transmitting orders to the men aloft, or to the engineers. These are generally cylindrical and flexible india-rubber tubes, with orifices of bone or ivory in the form of cuplike mouth-pieces; a whistle is fitted into this mouth-piece. The whistle is sounded first to attract the notice, so that the person thus warned by the sound of the whistle which is put into vibration at the opposite extremity may come to the tube. He then repeats the signal in the same manner to show that he is there, and the conversation goes on in a low or moderate voice, taking care to place alternately first the mouth and then the ear to the opening of the tube.

Jugglers and others have not omitted to make use of this power of transmitting sound to a distance. M. Radau, in his *Acoustics*, quotes several amusing examples of these applications; the following is one we borrow from him:—

"The invisible woman, who, at the beginning of this century, excited such a great sensation in the principal towns of the Continent, is explained in a very simple way. The most obvious part of this machine (Fig. 65) was a hollow globe, fitted with four appendages in the form of trumpets, and suspended freely from the ceiling of a

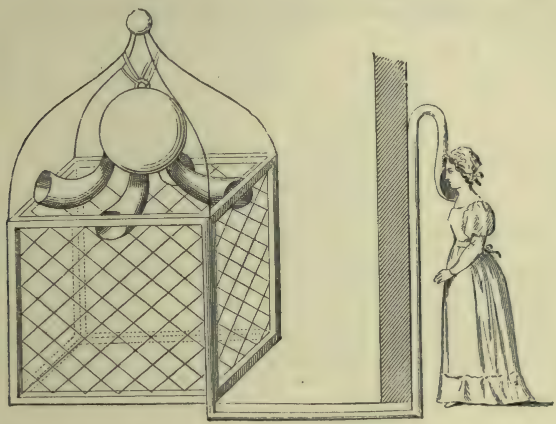


FIG. 65.—The invisible woman.

room, by four silk bands. This sphere was surrounded with a trellis-work cage, supported by four pillars, one of which was hollow and communicated with the ground. The acoustic tube which passed through it opened at the centre of one of the upper horizontal cross-pieces, where there was a very narrow slit, scarcely perceptible to the eye, opposite the orifice of one of the four trumpets. The voice seemed then to issue from the sphere. It is possible that the person who stood close at hand, and who gave the answers, was able to see through a slit in the wall all that passed in the room. The questions were asked through the orifice of one of the trumpets."

§ II.—THE SPEAKING-TRUMPET.

The human voice is also transmitted to great distances by employing an instrument much used at sea, called a speaking-trumpet. This is a tube of a conical form having at its narrowest end a wide cup-like mouthpiece; on putting it to the mouth the mouthpiece

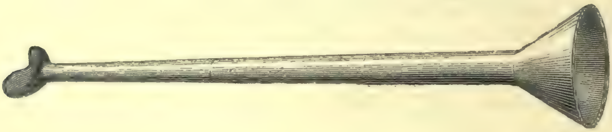


FIG. 66.—Speaking-trumpet.

covers it entirely, so that the movement of the lips can be made inside with ease. The opposite extremity, which is bell-shaped, is turned in the direction whither the sound is to be sent. Kircher in his great work, *Ars Magna Lucis et Umbræ*, and in his *Phonurgia*,

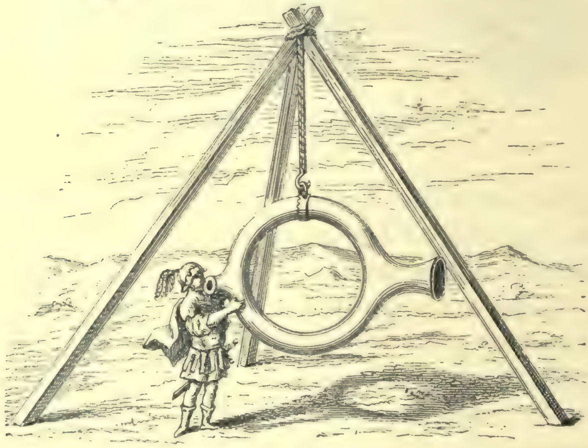


FIG. 67.—The horn of Alexander the Great (Kircher).

mentions a kind of gigantic speaking-trumpet, described as the horn of Alexander the Great, which was used in the armies of the Conqueror to recall soldiers even at a distance of a hundred stadia. It is certain, however, that the speaking-trumpet is of modern invention and

we are indebted for it to Samuel Moreland, 1670. A glass or copper trumpet was first used.

Since that time, elliptical, hyperbolic, and various other forms have been given to these instruments, and a theory has been formulated to explain the strengthening of the sound by the successive reflections of the sound-waves on the inner walls of the tube. According to Lambert, the wide conical form has the effect of rendering the reflected

FIG. 68.—Speaking-trumpet in the merchant service.

rays on leaving the tube parallel to the axis in such a manner that they are all directed towards the point to which the sound is required to be carried. The surfaces which are convex towards the axis are therefore useless. But Hassenfratz found by experiment, with two similar

speaking-trumpets, the one furnished and the other deprived of its bell, the first carried the ticking of a watch placed inside it double the distance of the second. Thus, the explanation is inexact, or at any rate incomplete. It is probable that the strengthening of the sound in speaking-trumpets depends chiefly on the form of the column of air in the interior, and that the walls themselves and the reflection of their surfaces have little influence—a view also confirmed by another experiment of Hassenfratz, who covered the tube with woollen stuff, without weakening the sound or its range. The influence of the bell is not explained.

The speaking trumpets used at sea are about 2 metres in length, the diameter of the bell being 30 centimetres. In England, much longer ones, which carry the voice to a distance of nearly 4 kilometres, are used. When an inarticulate sound only is made a good speaking-trumpet may be heard at 5 or 6 kilometres distance. On ships, the masters also use whistles for transmitting orders to the sailors. We shall again meet with this acoustic instrument further on, its uses are so numerous and its sounds attain such great intensity when they are produced by steam as in locomotives.

§ III.—Musical Telephone for transmitting Military Orders in the Army or at Sea.

The idea of employing sounds as a means of military signalling is doubtless very ancient. It is known that the Gauls posted at distances within range of the voice sentries charged with transmitting orders or communicating military news. But they had no particular system which ensured the secresy of the communications as in the musical telephone of M. Sudre, which we will explain.

As early as the year 1817 this physicist entertained the idea of substituting musical sounds for ordinary language by diversely combining a certain number of musical notes, and ten years later, he proposed the adoption of his system for the transmission of orders in the army. Instead of using the seven notes of the gamut, he confined himself to the five notes C, G, C, E, and G, the sounds given by the regulation trumpet. Some experiments were made in 1829 at the Champ de Mars, in 1841 in the Mediterranean fleet, and in 1850 from the Champ de

Mars to Rueil; they were very satisfactory. M. Sudre had reduced the sounds to three notes: G, C, G. Later on he succeeded in not using more than one sound, so that one note of the clarion, one beat of the drum or one cannon-shot, might at pleasure and according to the circumstances be used as elements of military sound signalling. A system of correspondence of this kind was established at Sebastopol during the siege, and rendered service to the besieging army by preventing the reserve from nocturnal attacks which the Russians directed towards those working in the trenches.

Musical signalling cannot rival either the electric telegraphy or visible signals. But there are cases where neither one nor the other of these can be employed, and where it can then be advantageously adopted.

§ IV.—Ear-trumpets—The Stethoscope.

The ear-trumpet is an instrument which has another kind of interest, particularly appreciated by persons suffering from partial deafness. It strengthens sounds, like the speaking-trumpet, by condensing them within a short distance and in the ear of the listener.

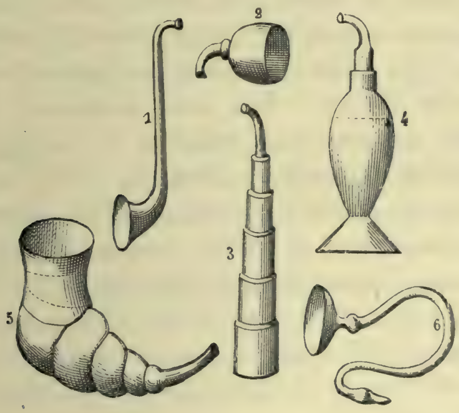


Fig. 69.—Ear-trumpets.

The ear-trumpet is a conical tube, made in various forms, which the deaf person holds in the hand, introducing the smaller extremity into the ear, and turning the bell towards the mouth of

the speaker. The reinforcing effect of the ear-trumpet has been attributed to the successive reflections of the sound-waves, which multiplies their action on reaching the tympanum. But, as in the speaking-trumpet, experiment has shown that the influence of the walls, and consequently the reflection of their inner surface, is very feeble, if any at all. The effect produced is in reality owing to the progressive diminution of the sections of the air-surface which transmit the sound, and which then transmit it with increasing energy towards the organ. This effect may be compared with that of a jet of water which issues from the orifice of a hose with a much greater force than that of a body of water of equal diameter in the interior of a pump-barrel.

The stethoscope is a kind of ear-trumpet invented by Laennec, and used by physicians to study chiefly the sounds produced in the interior of the chest by the action of the heart. This is a wooden cylinder, widened out at the end applied to the body, and pierced with an opening some millimetres in diameter, at the extremity of which the ear is applied. M. Kœnig has invented a new stethoscope based on the refraction of sound-waves. " It is composed of a small hemispherical capsule, in which a ring is placed covered with two india-rubber membranes. An opening made through the ring allows the inflation of these two membranes, in order to give them the form of a lens. The small capsule has at top a small tube made to receive an indiarubber pipe which puts the interior mass of air in direct communication with the ear. The outer membrane, thus inflated, is applied to the sounding body which is to be examined. It then takes the form of this body, receives the vibrations and communicates them to the opposite membrane by the intervention of the inclosed air; the second membrane afterwards communicates them to the tympanum by means of the air contained in the capsule and tube. Five tubes may be fixed to the capsule without interfering with the clearness with which the sounds reach the ear, and then five persons are able to study the sounds at the same time."

§ V.—Acoustics applied to Architecture.

One of the most important applications which can be made of the laws of acoustics is that of the construction and arrangement of large public buildings. With respect to these, numerous attempts have been made, but few have succeeded, and the reason is doubtless that the architects who have tried them were more engrossed with the question of art than that of science; perhaps also the want of special knowledge has had a great deal to do with this almost general failure.

Public assembly-rooms may be divided into three categories, the requirements of each not being the same in an acoustic point of view. First of all, there are concert-rooms for which clear and distinct hearing is the principal object: the orchestra and the spot where the singers are placed form the sound focus, whence diverge all the waves which ought to strike the listener's ear, wherever he is seated, under the best conditions, so that the finest shades of the melody may be perceptible to him without losing the harmony of the whole. Here sight may be sacrificed to the ear, as it is not properly speaking a spectacle, and all is confined to the hearing of a piece of music. Chance has sometimes united these conditions, and the concert-room of Music in Paris of the Conservatoire is an example of it, according to the general testimony of amateurs and artistes.

Lyrical theatres form an intermediate category between concert-rooms and those intended only for listening to an orator or actors. Music is here again the principal object, but the problem is complicated by the necessity of leaving the stage visible to all the spectators. Moreover, the sound-focus is here double, for it consists, on the one hand, of the orchestra, and, on the other, of the stage where the singers are placed. The ordinary comic or dramatic theatres are almost in the same difficulty.

Halls for courts and deliberating assemblies form the third class of places of meeting. Here the distinctness of hearing is the first and nearly the only difficulty to solve, as the room is not extensive enough for the sound-waves to lose their intensity before they reach the most distant hearer.

By carefully analysing all the causes of defect in present buildings, and taking into account the laws of the propagation and the reflection of sound waves, we should be able doubtless to solve the difficulties of the problem. Some of these rooms fail, either for want of, or an excess of, sonorousness. The form of the walls or sides of the room first of all has a predominating influence. Often the voice and sounds are absorbed by very considerable masses of air, in which the sharp force of the sound-waves is lost before they are able to reach the ear of the listener. Too great height of ceiling or roof, too great length from the stage and side-scenes, too great depth of the boxes, often hung with woollen stuffs and deadening draperies, make a room dumb and at the same time little favourable to the emission and to the hearing of the singer's or orator's voice, as also to that of instrumental sounds.

Rooms with walls having a form which give to the reflected waves different centres of convergence, or composed of substances which send back the sound with too much promptness, have the opposite defect. They have an exaggerated and intemperate sonorousness, besides being very unequal; they resound, and the listener hears both direct and reflected sounds, confusion follows, if speech is in question, and most disagreeable discord in the case of musical sounds.

The rules to be observed to remedy these serious inconveniences can only be general, or at least they are susceptible of modifications according to the circumstances of their general application. For the most part, they are reduced to a combination of very simple acoustic laws with the laws of architectural construction.

The following is what is said touching this by M. Th. Lachez, the author of a small treatise on "*L'Acoustique et Optiques des Réunions publiques*," who is at the same time an architect. We will only quote that part of his opinion which refers to the three classes of rooms to which we have referred.

"*To cause musical sounds and singing to be heard.*

"Whether the music be played in an unlimited space or in an inclosure shut in on every side, it is possible that the audience may see nothing in either case, and take in all the sounds, without looking at the instruments which produced them. Thus to fix the place where the sounds are produced, in the most convenient spot, and in the most favourable circumstances, in order that the sounds should be

rendered more perceptible, richer, and more harmonious, is the principal, if not the only, end to be achieved.

"If the orchestra is in the open air, the audience should be grouped circularly round the orchestra, in order to be in the simple and natural extension of the sound-waves; the orchestra being raised above the audience, so that the shock of the waves is outside the mass of air occupied by the audience, and that the sounds are able to come out and free themselves easily."

The author remarks that a parabolic ceiling, or circular, or polygonal wall, can only be used with advantage when their distance from the sound-focus is small enough to insure that there shall be neither resonance nor intemperate reflexion. For an amphitheatre closed in on every side, the arrangements would be the same; nevertheless, instead of placing the orchestra at the centre, it would be necessary to place it at the side, and the singers must face the audience.

As to the limiting walls, they should be upright and smooth, and their surfaces should be resisting and polished;[1] large projections, ornamental recesses, or excrescences must be avoided; hangings should only be used for deadening the excess of sonorousness in the room.

[1] General Scott, the distinguished architect of the Albert Hall, does not agree in this, he considers that the tone is thus made very harsh. He writes :—"In considering the mode in which the interior walls of the Hall should be finished, three courses were open to me, each one of which has advocates whose opinions on such a subject merited attention. The first course was to discard resonant materials as far as possible. Those who think that this is the right course argue that after the sound has reached the ear the sooner it is absorbed the better, and that any degree of resonance from the walls of the building is detrimental to musical effects. A second course was to finish the walls with hard, well-polished plaster, and to lay the floors with tiles. This is the opinion of one of the most distinguised organ-builders of the day. A third course was to line the walls with a resonant material, and I decided on the plan of using wood, for the following reasons :—1. The buildings most remarkable for their acoustic properties have been all so finished. The celebrated theatre of Parma, Her Majesty's Theatre in the Haymarket, which was destroyed by fire, the Surrey Music Hall, which shared a similar fate, and the theatre of the Royal Institution, were all lined with wood. 2. It is a generally received opinion that a room sufficiently non-resonant for speaking is too dead for musical purposes, and that the resonance derived from wood is more beautiful than that obtained from other materials. 3. The correction of undue sonority by draping is a simple matter, but it would have been costly to have imparted resonance to a building deficient in this respect."—ED.

"*To cause the speech of an orator to be heard.*

"In this case, if not necessary, it is at least of great utility, to inclose the audience and speaker in a space shut in by walls; and, according as this space is more or less extensive, the speech will be more or less perceptible to a certain number of people. An inclosed space has not only the advantage of being protected from all extraneous sounds, and from atmospheric inclemency; but it ought both to increase the sonorous intensity of the voice and to destroy the resonance which takes place in consequence of the repercussion of the waves; the dimensions of the space and its volume, determine the acoustic means to use."

The arrangement of the auditors relatively to the sound-focus has much to do with the qualities of a room in an acoustic point of view. Generally, a series of seats arranged in a half circle with respect to the focus, orchestra, or tribune, allowing a normal view, or at least that the sounds shall be received directly, is preferable, provided that the line of these seats be gradually inclined above the horizontal plane along which the sonorous waves proceed.

In theatres, where we have both orchestra and stage, and where seeing must be considered as well as hearing, the conditions of the problem are more complex. They are still more so, as the architect is obliged to take into account traditions, customs, and routine.

CHAPTER II.

MUSICAL INSTRUMENTS—SIMPLE INSTRUMENTS.

A STUDY of the various instruments by the aid of which musicians utilize their art, considering each of them in connection with the laws of sound, would be extremely curious, but both delicate and difficult. Among all nations and in every age of history, and as far back as the most remote savage people, similar instruments have been found, from the clumsiest attempts to the studied forms of modern violins, imitated from Stradivarius, Guarnerius, or the Amati,[1] and the complicated combinations of large cathedral organs. The theory of musical instruments is still on many points very obscure, and the ablest musicians, like the most learned physicists, find it difficult to account for the forms which experience has established. Nevertheless there is a certain number of principles on which the construction of musical instruments is based; and it is interesting to see how these principles are connected with the laws of the sound vibrations produced by bells, strings, pipes, and membranes.

This we shall endeavour to show by reviewing the types of instruments the sounds of which are produced by different modes of vibration, which can then be arranged in classes. We shall therefore examine successively: 1st, those simple instruments which generally give but one sound, such as bells, triangles, drums, etc.; these are based on the vibrations of solids of revolution, of metal

[1] Celebrated musical instrument-makers of Cremona, who occupied themselves chiefly with the manufacture of violins and stringed instruments and bows. The Amati were three brothers, one being master of Stradivarius, who had Guarnerius as pupil.

plates, or of membranes; 2nd, stringed instruments; this numerous family may be subdivided into three principal branches, the types being the violin, harp, and piano; 3rdly, wind instruments, which are also divided, according as the mode of production of the sound depends on the mouthpiece—an orifice as in the flute, a mouthpiece as in the horn, a reed as in the clarionet; the flute, horn, and hautboy may serve as types of these three kinds, which are all contained or imitated in the organ, that magnificent *ensemble* where all instrumental tones find expression, and which alone replaces a whole orchestra.

§ I.—Instruments based on the Vibrations of Rods or Plates.

Plates and metallic rods of different forms vibrate when they are rubbed transversely or longitudinally, or are struck in any one of their points. Sounds are thus given out which are sometimes used in musical bands.

The triangle is an instrument of the last class, formed of a cylindrical rod of untempered steel, bent in the figure of an equilateral triangle open at one of its sides; sometimes metal rings are added strung on to the base. The performer strikes one of the sides of the triangle with a steel rod. From this percussion there follows a series of harmonic sounds the coexistence of which gives to the instrument its sonorousness. This instrument contributes neither to harmony nor melody, but it accentuates the rhythm of a piece.

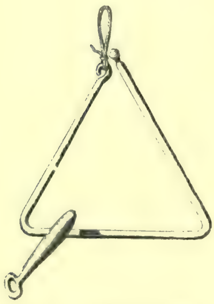


Fig. 70.—The triangle.

The harmonica, with plates of glass, is an instrument formed of a series of glass plates, the sizes of which are calculated in such a way that when struck properly the successive sounds of the scale are given out: the plates being of the same breadth and thickness, the squares of their lengths are in inverse proportion to the number of vibrations of the notes of the scale. The plates are supported by horizontal strings in a strong wooden box. The strings support the

plates at the nodal lines corresponding to the fundamental note of each of them. The notes are struck with a kind of hammer with a cork head. The notes have a very pure clear tone. The negroes' castanets are harmonicas in which wood replaces glass and which has no sounding-box. Lastly, metal plates arranged in the same manner as in the glass harmonica, and struck alternately or simultaneously with a hammer moved by a keyboard, form a sort of carillon.

Instruments of this class are of very early origin and found in almost all nations; generally they are perfected by the addition of resonance globes or tubes, the air in each according in vibration with the note of the slab of wood or plate of metal suspended

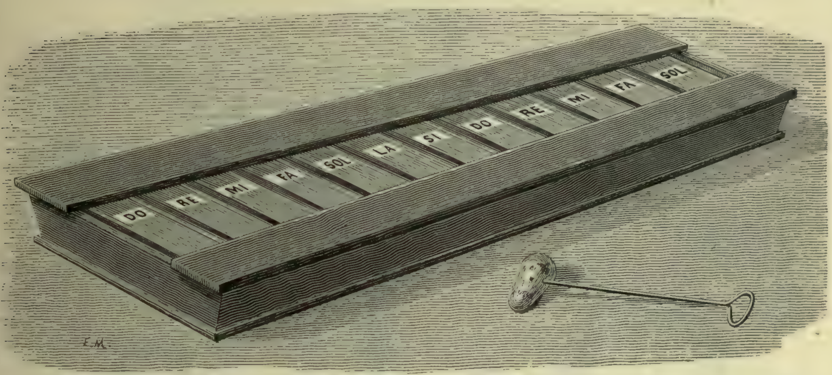


FIG 71.—Harmonica with plates of glass.

above them. Hollow gourds and pumpkins are chosen for globes and tubes, in sizes forming a series. The "Gender" of the Javanese is a notable representative of the kind possessing bars of sonorous metal.

The name of Musical-Box is given to automatic instruments in which the notes are produced by small plates of steel or copper arranged like the teeth of a comb; the dimensions of these plates are calculated so as to give the notes of the scale with their accidentals. The teeth are struck by small pins set round a cylinder, which is moved at a uniform rate by clockwork. The box in which this mechanism is inclosed gives more power and sonorousness to the notes emitted by these plates. The sonorousness is still more

increased by placing the instrument on a table. It is wound up by a key like a common watch. The cylinders are studded with pins so that many airs can be played at will by moving the cylinder.

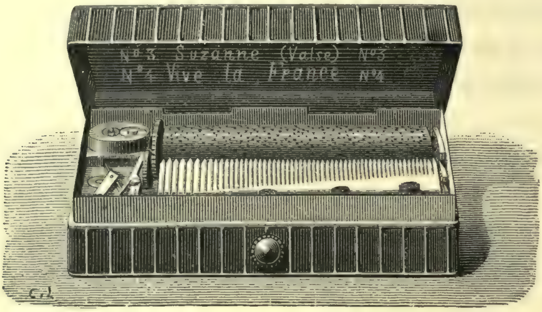


FIG. 72.—Musical-box.

Figures 73, 74, and 75 represent instruments known under the name of sistrums, and used in ancient Egypt. They were evidently based on the vibrations of metal rods. The Jew's-harp, with which

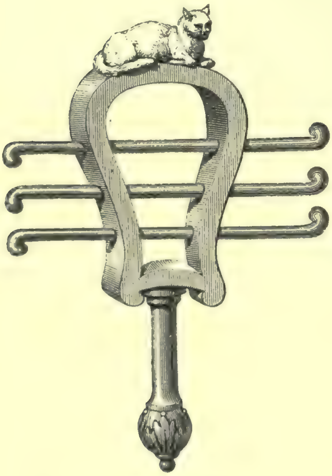
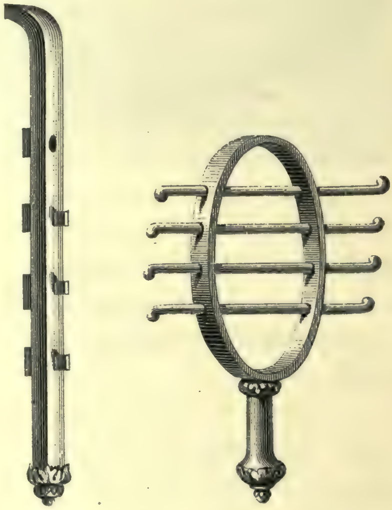


FIG. 73.—Sistrum of Isis.



FIGS. 74 and 75.—Sistra of the ancient Egyptians.

children still amuse themselves and which is probably of very great antiquity, is an instrument which may be classed among these. It is composed of a steel rod, free at one end and joined at the other to an

arc curved on both sides, which is placed between the teeth. The centre rod is then caused to vibrate by the hand; by opening or contracting the mouth, the sounds which proceed from the little instrument are modified in pitch and strengthened.[1]

Cymbals are used in our bands like the triangle. They consist of two circular bronze plates which the performer holds in each hand by straps, and strikes one against the other with a sliding movement. At the centre of each cymbal is a cavity of a hemispherical form; this helps in the production of the sound, which is sharper than that given by metal plates. This can be proved by stopping up the two cavities with pieces of paper; the sharp sound is no longer heard.

The sounds of cymbals have a certain similarity with those of a

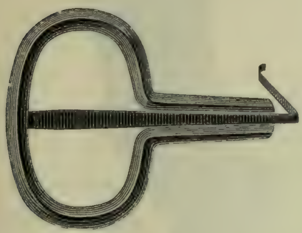


FIG. 76.—Jew's harp.

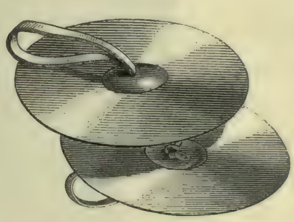


FIG. 77.—Cymbals.

Chinese instrument called a gong, gong-gong, or tam-tam. This is a bronze disc of a diameter varying from 50 centimetres to 1 metre, and surrounded by a projecting border. It is struck on the points near to the circumference with a stick having a pad covered with skin at the end. The repeated beats of the stick produce an extremely complex sound of singular sonorousness, which from time to time bursts out as if by explosion in tones which are sometimes shrill and sometimes deep. The impression caused by this odd instrument is most strange. The Chinese use it during marriages, burials, public or religious fêtes, and for visits of mandarins of high rank.

The Chinese distinguish gongs according to the intensity of their

[1] In the Jew's-harp, in fact, the mouth is a resonator capable of reinforcing aliquot parts of the reed's fundamental note.

sounds, which, however, depends chiefly on the manner[1] in which they are beaten, into male and female gongs. Japanese priests use the gong and cymbals in their ceremonies. Chladni relates that

FIG. 78.—Japanese bonzes or priests striking the gong and playing on cymbals.

this instrument was successfully made use of in an oratorio in Copenhagen to represent the earthquake at the death of Jesus Christ.

[1] See details relative to the making of tam-tams in *Les Industries anciennes et modernes de l'Empire chinois,* by Stanislas Julien et Champion.

§ II.—Bells and Carillons or Chimes.

Vibrating plates need not necessarily be flat, of rectangular or discoïdal form, they may be also shaped into hemispherical or ellipsoidal forms, as in bells, which are put to the most varied uses.

Bells of all kinds are most frequently used for giving signals, whether in every-day life or in works, railways, ships, etc. They are made of all sizes, and the notes which they give out generally are a composition of harmonic sounds produced by the parts of the sonorous body divided by the nodal lines. The deepest or fundamental note is that which most strikes the ear, and the mixture of the sharpest or highest notes gives to the bell the tone which is peculiar to it, and which the ear, although it can scarcely define it, easily recognizes.

Church bells have from time immemorial an almost traditional form, of which Figs. 79 and 80 represent a section and general appearance. The Japanese bell represented in Fig. 81 has evidently a very different form from that of European church bells.

In these, the outline and thicknesses of the metal at different heights of the bell are calculated so that the deepest sound produced by the vibration of the extreme edge or rim is an octave lower than the note of the head. Diderot writes that "The diameter of the head, when only half that of the rim, will sound the octave above that of the latter. The sound of a bell is not a simple sound, but is composed of different sounds produced by the different parts of the bell, in which the fundamental ought to absorb the harmonics, as it is said to do in the organ; if the perfect harmony C, E, G, be sounded together, the higher G, E, G, B, G, B, D are sounded at the the same time; nevertheless only C, E, G are heard at a distance, or perhaps only C. The ratio of the height of the bell to its diameter is as 12 to 15, or in the ratio of the fundamental to the major third: whence it is concluded that the note of the bell is principally due to the vibration of its rim, as fundamental, into that of the crown, which gives the octave, and that of the height, which gives the third. But it is evident that these dimensions are not the only ones which give out tones more or less deep; in the entire bell there is no part of the circumference

which does not produce a note depending upon its diameter and distance from the head." The determining elements in a bell's pitch may be generally represented by the "compromise" note of unison *rods* A, A, starting from the head, and constrained by the ring effect of the circumference.

The illustrious encyclopedist also makes reservations on the rules by which it is supposed that the tone of a bell can be determined by its form and weight: he states that "it would be necessary to calculate the elasticity and cohesion of the portions of the materials of which they are cast, two elements on which only vague conjectures can be formed." Experiment and the ear determine it with most certainty.

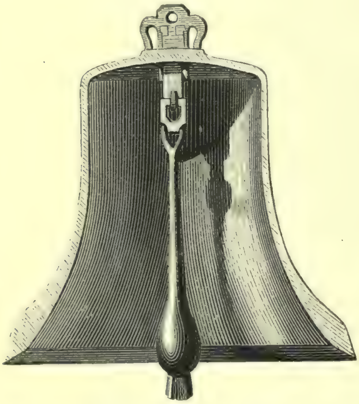


FIG. 79.—Section of a bell.

FIG. 80.—Outside view.

Contemporary physicists admit that, other things being equal, the dimensions of masses of similar form and material are in the inverse ratio of the corresponding dimensions. It is by means of this law that a series of bells of different dimensions, giving out the successive notes of the gamut and their modulations, can be produced. Figure 82 represents an ancient instrument of this kind called *sonnantes*, the bells of which, struck by two rods, were fixed on a box which strengthened the tone. It was a kind of harmonica with metal bells. Franklin's harmonica consists of a series of glass bells, or simply glasses with feet, which are put into vibration by friction; this is done by the fingers or a ribbon being wetted, and rubbed against the edges of the vessels. By pouring more or less

water into each glass, harmonies can be produced as exact as may be required.

It must be understood that most of the instruments of this kind are seldom used: they are mere objects of curiosity, interesting as applications of the laws of musical acoustics.

FIG. 81.—Japanese bell at Kioto.

Carillons, or chimes of churches and belfries, are collections of the same kind as those just described; they are formed of bells struck by hammers, the hammers being moved either automatically by the bolts of a cylinder, or directly by the keys of a finger-board, like that of an organ or piano, or, lastly, as in the primitive carillons, by a system of pedals worked by the hands and feet. The key-board

carillons constitute an important improvement on the two other systems. The carillon placed recently in the tower of Saint Germain l'Auxerrois is of this kind. This is composed of forty-two bells of different sizes.

In the towns of the north of Europe, as at Bruges, for instance, the striking of the public clocks at the hours and half-hours is preceded by an air automatically played on the chimes. The famous carillons of Bruges, Dunkerque, and other northern towns are constructed with a mechanism similar to that of musical boxes; but the cylinders are enormous, and the teeth on their surfaces lift up heavy hammers which strike on a series of bells tuned to the notes of the

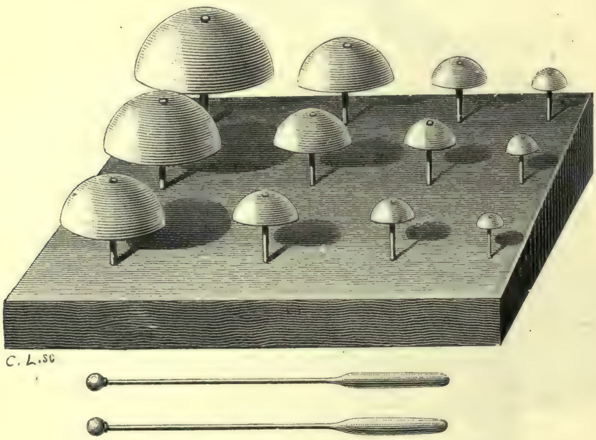


FIG. 82.—Sonnantes.

scale. Movement is given to the cylinders by wheelwork, which the belfry clocks set in motion every hour or even at the halves and quarters. To set these enormous machines in motion, it is necessary to have weights of several hundreds and even thousands of kilogrammes carried by chains which are wound on drums by means of a windlass. To wind them up daily, two or three men working from half an hour to three hours are required.

But this ancient system of chimes, which was itself an improvement on the primitive system represented in Fig. 83, has been much simplified in the carillon at Saint Germain l'Auxerrois which we have just mentioned, and represented in Fig. 84. This

new arrangement is due to M. Collin. The following is a description of it, by M. G. Sire, director of clock-making at Besançon:—

"The principal points of this new system of carillon are the following: First, a special wheelwork is used for each bell proportioned to its weight; secondly, the unclamping of the machinery which is used to raise the hammers, of which there are four to each bell.

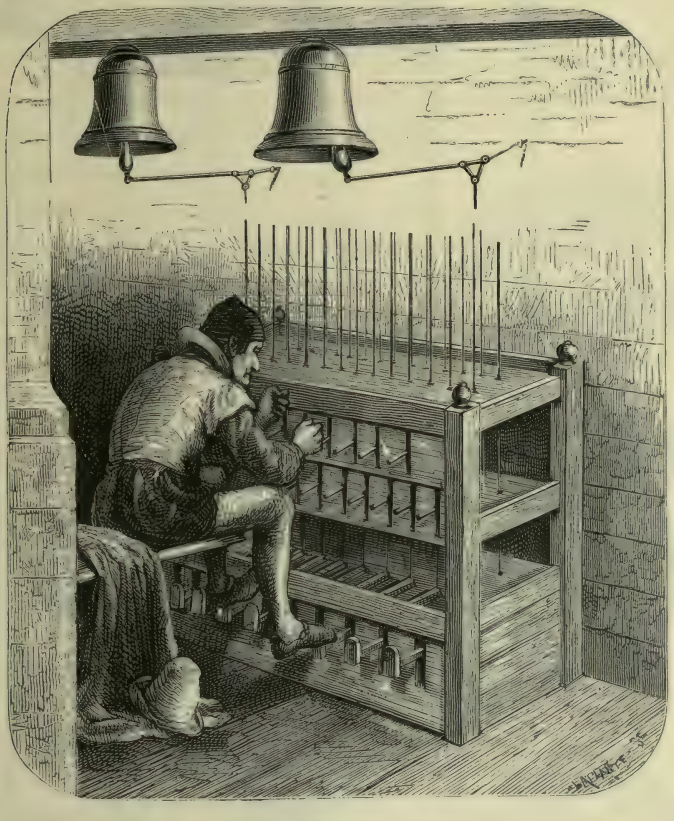


FIG. 83.—Old arrangement for chimes.

These fix themselves one after the other on a catch which holds them back, and from which the finger or pin of the cylinder with a very slight effort unclamps them and makes them strike the bell, on which they fall instantaneously and produce the note so sharply that one is able to play if necessary double and even triple quavers, which, however, is not required with bells; and at the moment when the finger

unclamps the hammer, the wheelwork is set in motion to place a fresh hammer on the catch ready for the fingers to free in the repetition of the note."

The difference between the old system and that of M. Collin

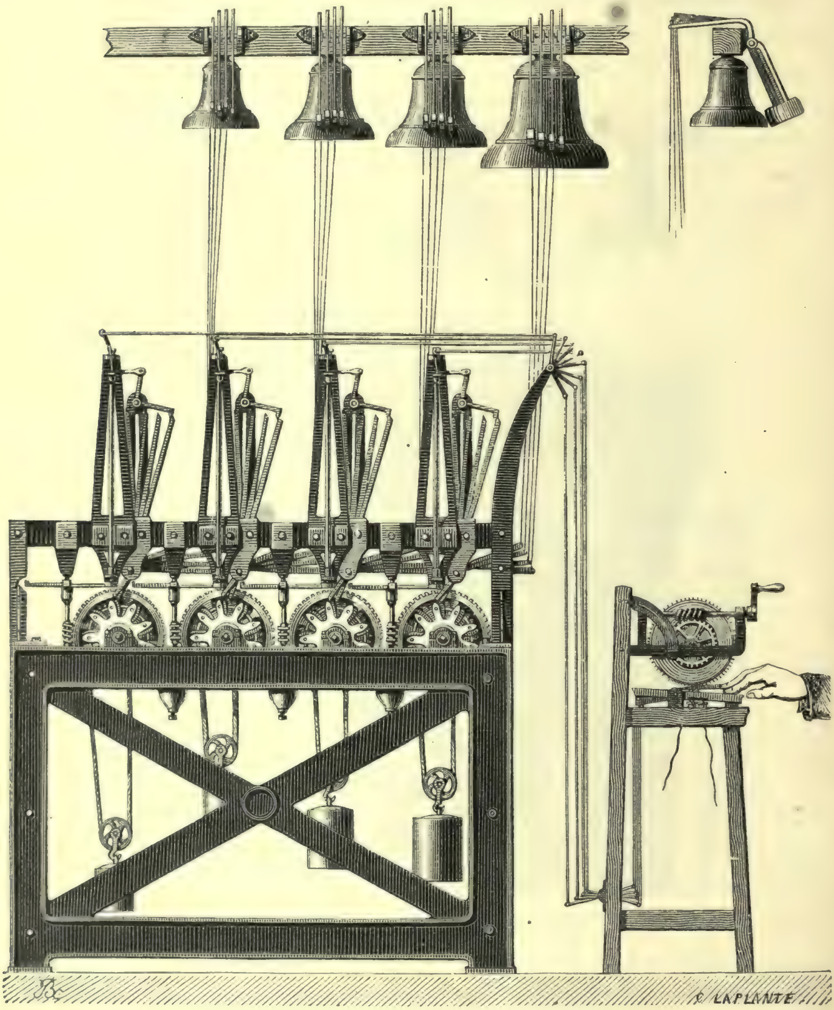


FIG. 84.—Modern key-board carillon at St. Germain l'Auxerrois.

consists then, instead of directly lifting the hammer, in using an intermediate mechanism between the lever and the key which reduces the work to a minimum.

Hence it follows that electricity may be used as a motive power; and, indeed, the carillon at Saint Germain l'Auxerrois, besides having an ordinary key-board, possesses also an electric one. "Thus it would be possible," says M. Sire, "for the organ in a church to play the chimes: this would be quite a new effect."

§ III.—Drums.

We have now come to the simple instruments of which the sounds are obtained by stretched skins or parchment, and are generally reinforced by a box. They are usually called drums and kettle-drums.

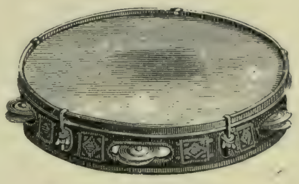


Fig. 85.—The tambourine.

The most simple of these instruments is the tambourine, formed of parchment stretched over a cylindrical hoop, and furnished all round with small bells or small plates of sounding metal. The instrument is held in one hand and is struck by the back of the other, or the thumb and fingers are passed over the

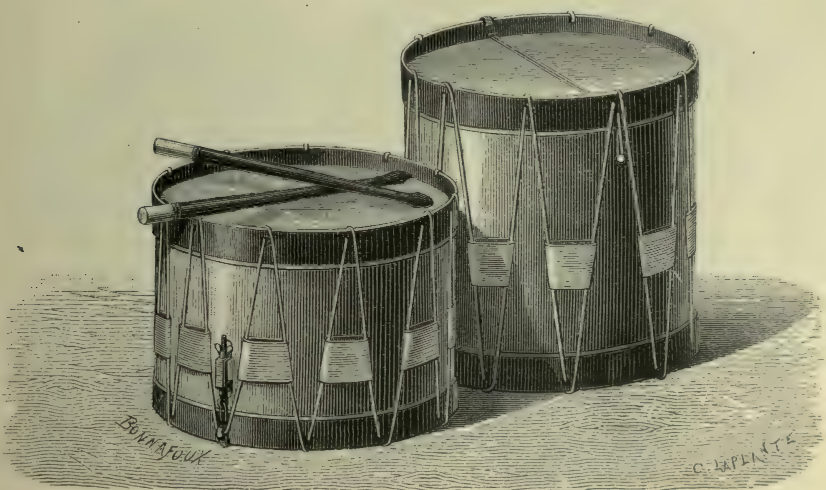


Fig. 86.—European military drums.

surface. This gives both a rhythmed vibration of the parchment and sounds produced by the shaking of the little bells or plates.

The military drum is composed of a brass or wooden cylinder, covered at the two ends with two skins stretched out by hoops,

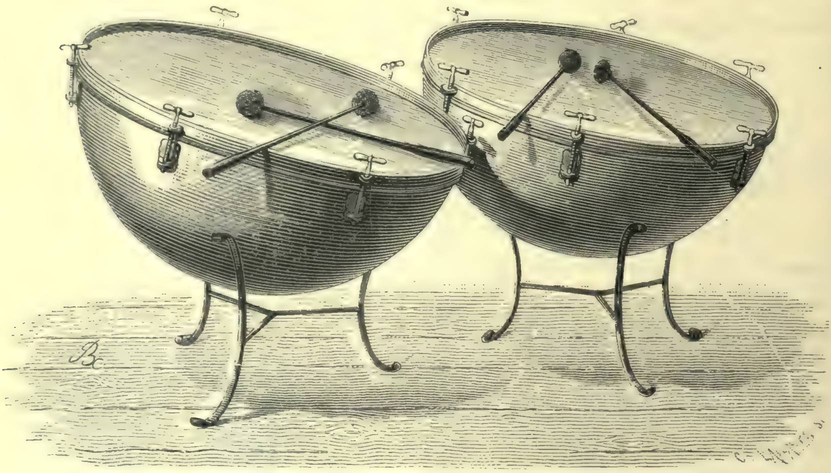


FIG. 87.—Orchestral kettle-drums.

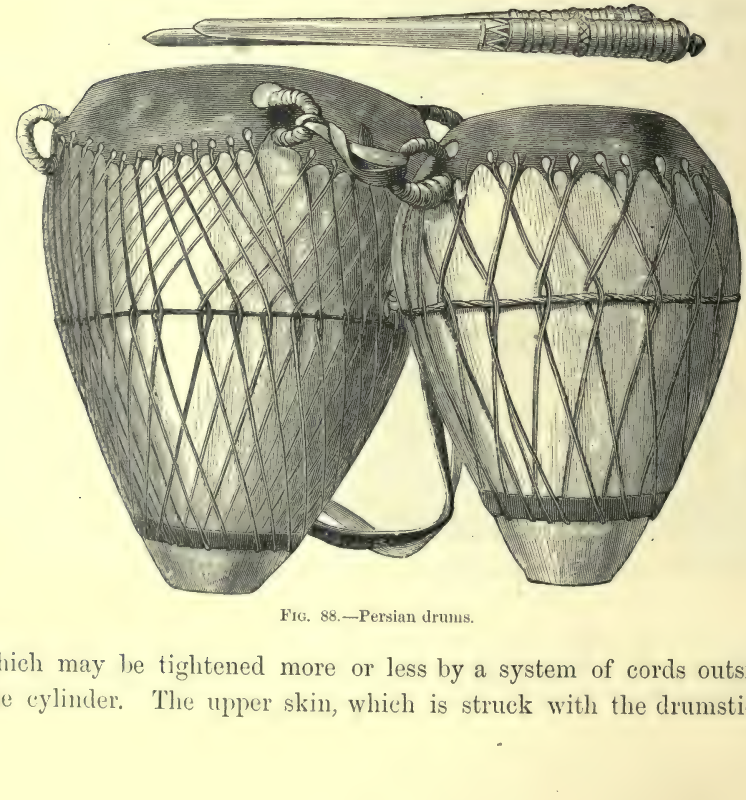


FIG. 88.—Persian drums.

which may be tightened more or less by a system of cords outside the cylinder. The upper skin, which is struck with the drumstick,

is thicker than the lower one, which vibrates under the influence of the cylindrical mass of air inside. Two catguts are stretched across the drum and placed against the skin; in vibrating, they strike the skin and give a peculiar tone to the note.

FIG. 89.—The Hing-Kou.

Drums can be made with notes which together form a musical harmony of a third, fifth, or octave. For this they must be of homologous dimensions in the inverse ratio of the numbers, 1, $\frac{5}{4}$, $\frac{3}{2}$, 2, that is to say, proportional, for instance, to the numbers 30, 24, 20, and 15. This is the law of the vibrations of the columns of air inclosed

in drum cylinders. Drums can be tuned a whole octave by various contrivances for straining the membrane.

Kettle-drums are a species of drums in which the skin is stretched over a metal box rounded underneath: they are used in the cavalry. The drummer carries this double drum on either side behind the pommel of his saddle, and he strikes it with balls covered with leather; in this way they give out a more agreeable sound than if they were struck with an ordinary drumstick.

These instruments have been introduced into our orchestras, but care is taken to tune them to a third or some other musical interval, by constructing them of different sizes, and by stretching the skin more or less tightly.

The drum is a very ancient instrument, and under diversified forms, widely spread in civilised and barbarous countries. The tambourine, used in village *fêtes* in Provence, is an elongated drum which the performer beats with one hand, accompanying himself on a little three-holed flute. One of the most original forms of the drum is that of the Japanese tambourine represented in Fig. 89. This is the hing-kou; the performer strikes the skin with two sticks; the instrument rests on a double stand or foot, which prevents the vibrations from being dulled by the ground.

CHAPTER III.

STRINGED INSTRUMENTS.

§ I.—Ancient Stringed Instruments.

STRINGED instruments may be traced from the most remote period. We know that David played on the harp before the ark sacred to the Jews, and the sounds which he drew forth were so melodious that Saul was preserved from being tormented by the devil. It is not known whether this harp was the hazar, the kinnor, or the

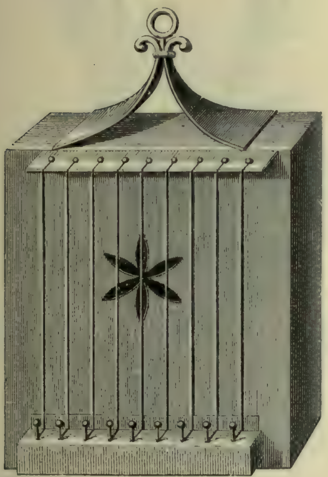


Fig. 90.—The hazar of the Jews.

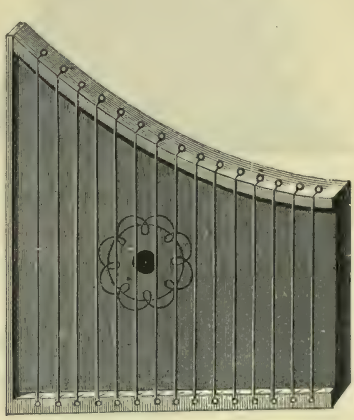


Fig. 91.—The nebel.

nebel, represented by figures 90, 91, 92, and 93. But it is certain that the term always refers to instruments composed of a sounding-box of wood or metal, to strengthen the notes of the strings stretched

over one of its sides. The harp used by David must have been a portable instrument, as he danced at the same time that he played and sung.

The lyres or citharæ of the ancient Greeks were instruments similar to those of the Jews. Four, five, seven, nine, or more stretched strings, communicating their vibrations to the supports and cases, which took various forms, of which they were constructed, then to the masses of air inclosed in them; such were the instruments which were chiefly used to accompany the voices of rhapodists or poets. The strings were pulled with the fingers or struck with the

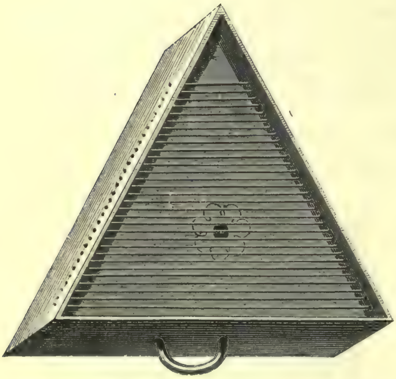


FIG. 92.—The kinnor.

FIG. 93.—The harp of the Hebrews.

plectrum, a rod of ivory or polished wood which the performer held in his right hand.

Who was the inventor of the lyre? According to the ancients, Mercury or Apollo, for they could not imagine that too noble an origin could be given to such an enchanting art as music. Had not Orpheus, by playing on the lyre, tamed wild beasts, moved trees and rocks into tears, won over Cerberus, and touched even inexorable Pluto, when he dragged Eurydice to the infernal regions?

But we will here leave fable, however ingenious and touching it

may be, and call to mind only that the Greeks studied the lyre not only as artists or poets, but as physicists, for they understood the

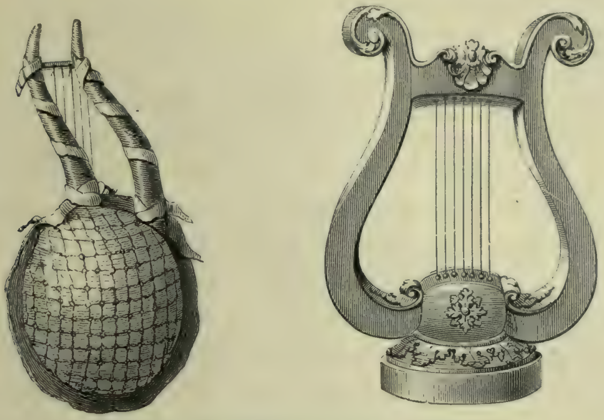


FIG. 94.—The tetrachord and the heptachord.

relations of sonorous intervals and lengths of the strings, the discovery of these laws going as far back as the time of Pythagoras.

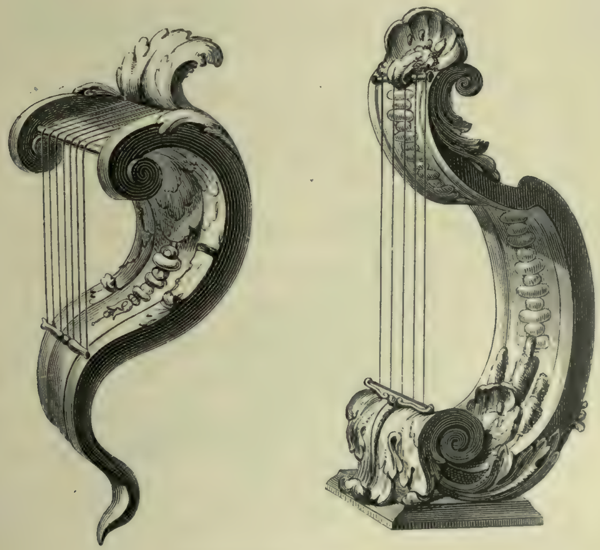


FIG. 95.—Ancient lyres or cithars.

We now come to modern instruments, the construction of which is based on the vibration of sonorous strings, and which like the

ancient ones are composite: the sounds of the strings being too feeble by themselves, they are strengthened by boxes in which the included air and sides enter simultaneously into vibration.

We shall divide them into three classes, according to the method of vibration of the strings. In the first, we shall group the bow instruments of the violin class. In the second, the instruments with strings which are plucked or pulled, either by the fingers of the performer, or by a point of wood or quill; an example of this class is the harp or guitar. Lastly, our third class will include instruments with strings which are made to vibrate by the fall of a hammer; these are instruments with keys, of the piano class.

It is clear that another classification would be possible, that we could distinguish between instruments with fixed lengths, each of which only gives one note, and those with strings which can be shortened at will by the performer, and therefore are susceptible of variation either in a limited or indefinite manner. It would be possible also to arrange them according to the nature of the substances of which they are composed, and of the tones they produce. But these different points of view only affect indirectly the subject of which we treat. We wish only to point out on what principles of musical acoustics the construction of each type of instrument is founded.

§ II.—The Violin.

We will begin with the most perfect of musical instruments, the violin. As in most stringed instruments, we have to study, first, two principal parts, from a sound-producing point of view, one being the system of strings from which the sound originates, the strings being put directly into vibration by percussion produced either by plucking with the finger or by the friction of a bow; the other part consisting of a hollow box or chest on which the strings rest, and which is intended to strengthen the sounds produced and to give them the qualities of power, sweetness, and mellowness, and to impart to the instrument its peculiar tone.

The sides of the box and the mass of air contained in it contribute in a certain measure to this result. We will describe these two parts with special reference to the functions they have to perform.

PLATE VI.—JAPANESE MUSICIANS.

The sounding-box of a violin is formed of two almost similar plates, A B, shaped as shown in Fig. 96, and hollowed out at the middle of either side in order to give free passage to the bow in its movements backwards and forwards across the strings. The lower plate, or "back," is made of a hard and close-grained wood, generally of beech, as well as the lateral plates, sides, or ribs which connect it all round with the upper plate or belly. This latter is made of a light wood, either deal or cedar,[1] and it is strengthened inside by a piece of wood, C C, the "sound bar," elliptical in form and fixed longitudinally, and a little on one side of the centre line. The upper plate or belly is pierced on each side, at its narrowest part, in the positions, X Y, with two openings called "sound-holes," or more commonly "*f* holes."[2] Between the *f* holes is placed the bridge *e*, a small piece of wood with two feet, perforated in order to give it elasticity, and to prevent the sonority of the instrument being impaired, and also intended to serve as a support to the strings. These, which are four in number, are attached at one end to the tail-piece *d*, which is fastened by a string and button to the lowest part of the ribs or sides. This tail-piece has four holes made in it through which the strings are passed and fixed by a knot; at the other end, the strings rest on the nut *g*, and enter the hollow part of the head, D E, and are then wound on the pegs. Between the nut and the bridge, and below the strings, is the finger-board *f*, a convex piece of ebony which is joined or glued to the neck, and projects over the belly without being in contact with it. Lastly, between the two plates or the back and belly of the violin, and almost below the right foot of the bridge, that is to say, on the same side as the first string, or chanterelle, and on the opposite side to the sound-bar, is a small cylindrical piece of wood *a*, which is fixed vertically, so as to connect the back and belly, and is called the "sound-post."

Such then is the sounding-box of the violin. We will now proceed to consider the system of strings and their mode of arrangement

[1] Swiss pine or Swiss fir was preferred by the old Italian makers for the belly, on account of its feeble density and rapidity in transmitting sound; and maple for the back, as in this wood the propagation of sound is much less rapid than in deal.—TR.

[2] The "*f* holes" are of the form most suited to afford a connection between the outer air and that inclosed in the body—without destroying the continuity of fibrous surface; at the same time greater "play" is admissible in the face.

on the instrument. The arrangement consists of four cat-gut strings of equal lengths, but of unequal thicknesses. The thickest or

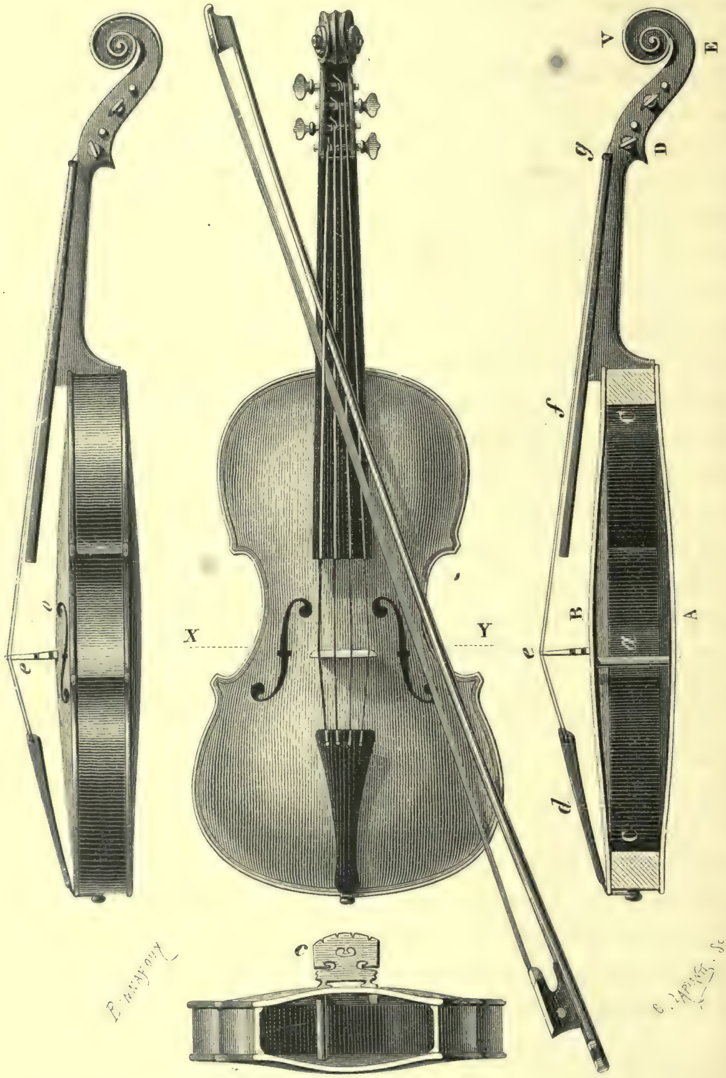


FIG. 96.—The violin: longitudinal and transverse sections. The violin viewed in front and at the side.

fourth to the left, is a wire string, that is, the gut string is covered with plated copper or silver wire, which gives to the notes produced

from it a penetrating and metallic tone. The smallest or first string is called in French the chanterelle, and is on the right side of the finger-board or the bridge.

By turning the pegs around which the strings are wound, a tension is given to them, so that at will, the height of the fundamental note may be varied gradually, according to the well-known laws of the vibration of strings. In this way, the instrument is tuned; after having taken the unison of the diapason which gives A (870 vibrations a second) with the second string on the left, the other strings are screwed up to give the following notes, in fifths:—

4th string (wire-covered) or thick string	. . .	G
3rd "	. . . .	D
2nd "	. . . .	A
1st " or chanterelle	. . . .	E

The violin having been tuned, the performer holds the instrument between the chin and the left collar-bone, resting the neck in the left hand, in such a way that the fingers may be placed easily on the strings at certain distances from the nut which vary according to the heights of the notes to be produced. The bow is held in the right hand, and by its friction applied with more or less force, puts the strings into vibration; its action being in a direction always parallel to the plane of the bridge, or at a right angle to the length of the strings.

Figs. 97 and 98 give the points where the fingers ought to be placed on each string, in order to produce the successive notes of the scale, with the lowest G for the initial note. It is quite clear that instead of passing from one string to another (which is done without changing the position of the hand, or, technically speaking, without "shifting") one can produce the same notes (at least the notes more acute than the fundamental note of each succeeding string) on a single string, by moving the hand forward towards the bridge, and placing the fingers at points at greater distances from the nut. This will be understood by looking at the diagram in which these positions are marked, as far as the middle of each string, this point corresponding to the octave above the fundamental note of each string.

One word now on the way in which the instrument vibrates when

the strings are touched by the bow. The bow is furnished with hairs equally and smoothly stretched out like a ribbon and rubbed with rosin, and when drawn across the string it produces a rapid series of shocks more or less distinct, which, according as the bow is moved up or down, displace the string to the right or left from its state of equilibrium and give it, at each short interval, a series of periodic oscillations, the velocity of which depends upon the length of the vibrating portion, the tension of the string, and its diameter. By these multitudinous and isochronous vibrations, a note is produced the pitch of which is determined by the number of vibrations within a second of time.

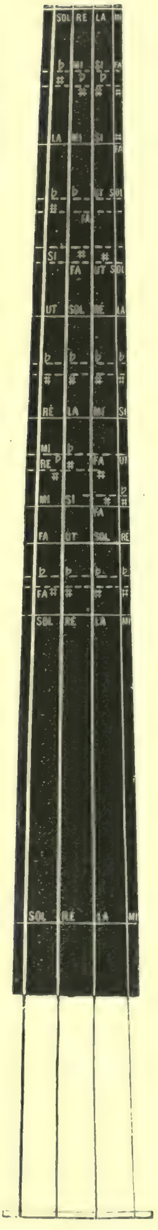


Fig. 97.—Finger-board of the violin.

If it were the string only that vibrated between its points of support, which are, on the one hand the bridge, and on the other the nut or the finger acting as a nut, the tone would be thin, without fulness, and without brilliancy. But by means of the bridge, the vibrations of the string are transmitted to the belly, and from thence, either by the ribs or sides, or by the sound-post, to the back and through the entire instrument. But the mass of air contained between these two plates has an important part to play through the vibrations which are communicated to it. It has the effect of imparting strength to the tone like a tube of large area and little depth, and this explains why it strengthens all the notes emitted by the instrument, although there are always, in the indefinite series of the notes of the violin, some amongst them which come out with more force and fulness than others.

The *f* holes are necessary to transmit the vibrations of the mass of air inclosed in the sounding-box, outside, to the exterior air. Without the *f* holes, the notes would be dull. Savart, who long studied the mechanism of the violin, in a series of remarkable experiments discovered that this mass

of air must be otherwise quite isolated; he found that by making openings in the sides, the tone became thinner in proportion as the holes were wider, and also that the vibrations of the plates were individually imperfect.

The sides of the sounding-box of the violin and the mass of inclosed air vibrate together in unison, as was also proved by Savart. Nevertheless, taken separately, the two plates ought to give two notes differing about a major second from each other. Nearer the unison, they would cause beats or throbs in the notes: further off the notes would be able to blend with difficulty. Moreover it is the upper plate or belly which vibrates with most power: this is the reason why it is necessary that the wood of this part of the instrument should be fibrous, elastic and light. The lower plate or back

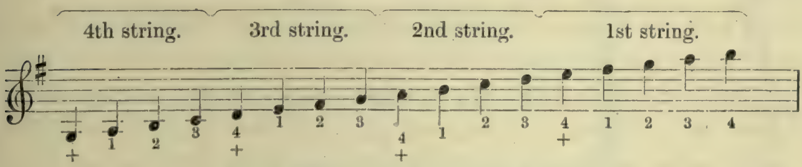


Fig. 98.—Finger-board of the violin; fingered.

is designed to give a reciprocating resistance to the motion transmitted from the belly; it has not merely to receive but to return the impulses and intensify the shocks. If it were only equal to the belly in rigidity only a see-saw motion would result adding nothing to the power.

The sound-post of a violin is a part of the instrument essential to the sonorousness and the quality of its tones. According to Savart, its function is to give out the normal vibrations of the two or conjoined plates. To prove his view, he pierced the two plates and vibrated the strings normally with the plates, by passing the bow through the openings; then the sound-post became useless.

M. Daguin[1] on the other hand, in noticing Savart's opinion

[1] The theory of M. Daguin is untenable. The possibility of transversal drag of the bridge is set aside by the fact that the acting string is one out of four, and the tension of each string averages 18lb.—54 against 18 holding the bridge in position. The bridge is really supported on both feet, one by the sound-*post*, the other by the sound-*bar*, else the strings least upheld by the *post* would burst the belly. The value of the present arrangement is in its securing everywhere responsive

respecting the sound-post, pronounces it inaccurate or incomplete, and the reasons he produces in support of this criticism appear very just: "Upon this explanation," he says, "one cannot understand why the sound-post must be under one foot of the bridge and not in the middle. A second post under the other foot ought to increase the effect, whereas it would in fact deaden the tone of the violin. Ought not the ribs, moreover, to produce the same effect as the sound-post? Upon due consideration, it appears to me that the effect of the sound-post ought to be explained in the following way. The sound-post has the effect of giving to one foot of the bridge a support by means of which the vibrations are communicated to the belly through the other foot. If one of the feet were not supported on a fixed point, it would rise up whilst the other would fall, because the strings do not vibrate normally with the belly, for the bow being in practice drawn over them very obliquely would, if the bridge had no fixed point, drag it in a transversal direction."

This is the reason also that the bridge has two feet resting on the belly. It is perforated because if its bulk were greater, the strings would only communicate feeble vibrations, and the sonorousness of the instrument would be diminished.[1] This is exactly what is done in passages which are to be played *pianissimo,* and are accordingly marked *con sordini,* that is, to be played with a mute. The mute, which is a piece of wood or metal fixed on the bridge, communicates to the notes of the instrument a peculiar tone of a muffled, dull, and melancholy character; pressure, however, answers as well as increased weight.

Savart, who made stringed instruments the subject of much study, tried to account for the influence exercised on the tone by the form of

elasticity. To the first string, the *post* secures by its direct pressure a special brilliancy, whilst the *bar* having less rigidity in support, although equal to its work, gives to the other strings a more mellow body and sympathetic fulness of tone. The sound-post is set back to ensure that the bridge gives its full transmission to the belly before its vibrations pass to the back, so that nothing is lost.—H. S.

[1] It was Stradivarius who finally determined on the present form of bridge; and it has been found that modifications of it tend to diminish the tone of a good instrument.

[2] The perforation has no reference to bulk; if the form is truly studied, it will be seen that it is a spring (as a carriage spring) —and no doubt Stradivarius saw the desirability of providing this reciprocity of action.—H. S.

the violin, and the nature of the substance with which the sounding-box is constructed. He himself made a trapezoidal violin, with flat plates and rectilinear sides, and this form in a musical point of view, had good qualities. But violins of glass, china, and metal, which have been tried, are worthless. Evidently, the specific lightness of the plates, the fibrous nature of the deal used for the belly, and its elasticity, are conditions essential to the regularity and fulness of the vibrations. The best instrument-makers know and apply the rules of their art traditionally: the variable thicknesses of the wood for the plates on the different parts of their surfaces, the quality of the wood, the relative proportions of each part of the instrument, the fitting, and lastly, and above all, the nature of the varnish applied to the outside surfaces of the violin, form a series of facts acquired by long practice and numerous experiments, the scientific analysis of which would be very delicate and difficult.

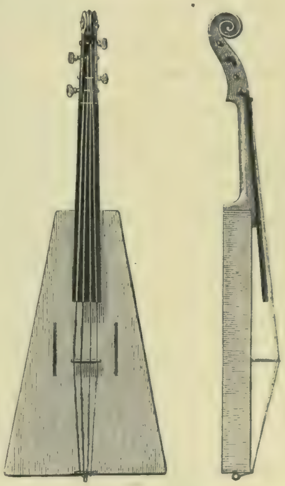


Fig. 99.—Savart's trapezoidal violin.

The age of violins, and their constant use in the hands of first-rate players, appear to have an effect on their qualities; it is possible that the elasticity of the fibres is developed under the influence of regular and accomplished playing. This is the opinion of artists and physicists of note.[1]

But it must not be forgotten that the beauty of the tone of an instrument of this kind depends, in great measure, on the talent of the artist in whose hands it may be. Nearly his whole skill, from this point of view, lies in regulating the pressure by which his right arm, or more properly speaking, his right hand directs the bow, and the clearness and force with which the fingers of the left hand press the strings. The purity of the notes, their power, mellowness, the thousand varied expressions, of which they are susceptible, all these marvellous qualities depend doubtless on the excellence of the

[1] Helmholtz says: "A great deal of the superiority of old violins may well be due to their age and long use, which two circumstances cannot but favour the development of the elasticity of the wood."

instrument to a certain degree; they are, however, chiefly dependent on the skill of the performer: the power of expression, and musical feeling, added to these material qualities, constitute his genius.

§ III.—Bow Instruments of the Violin Family.

All that has just been said of the violin may be applied to all instruments of the same class, of different sizes, but having almost the same form and construction, externally and internally, and played, like the violin, with a bow, and also by plucking the strings, termed, in musical language, playing *pizzicato.* The *tenor, alto,* or *viola,* which was also formerly called the *alto-viola,* is a violin of rather larger dimensions, tuned to the fifth below the violin, with two wire covered strings, and two ordinary gut strings producing as fundamental notes, C, G, D, A. Formerly the tenor was played by resting the instrument on the knees or on a table, with the same bowing as the violoncello. In the present day, it is held under the chin, and is used in precisely the same way as the violin. The *violoncello* is much larger than the violin or tenor, and tuned like the latter, only an octave lower. It is held between the legs of the performer, so that the bow is worked in a direction contrary to its action on the violin, the lower-toned strings being towards the right of the performer instead of the left; lastly, there is the *contra-basso* or *double bass* still larger, the open strings of which are an octave lower than the violoncello.

It may be interesting here to notice a singular defect observable in certain notes of the violoncello. In sounding a particular note on the third or G string, an unpleasant jarring tone is produced, termed by musicians the "wolf;" the note itself, which varies on different instruments, but is usually either the E or F, being termed the "wolf note." The same effect, though in a minor degree, is produced by the corresponding note on the second or D string. The "wolf" is found in nearly all violoncellos, even in fine instruments by the great masters, but science has hitherto failed to account satisfactorily for the defect. When the "wolf note" is sounded, the whole body of the instrument vibrates in an unusual degree, especially the belly, probably on account of the elasticity of the deal of which it is

constructed; but it has been found by experiment that by applying pressure, that is, imparting increased rigidity to that part of the belly where the vibration appears to be greatest, the "wolf" will entirely disappear. It has therefore been thought that if the belly could be

FIG. 100.—Instruments of the violin class: alto or tenor, violoncello or bass, and contra-basso.

strengthened or stiffened without adding materially to its bulk or altering its proportions, the desired result might be obtained. Accordingly the experiment has been tried of glueing small pieces of

light deal elliptical in form, like the "sound bar," longitudinally on the inner side of the belly across the *f* holes, where the belly is weakest. The result of this is that the "wolf" is, indeed, no longer perceptible, but, on the other hand, the quality of the tone of the instrument

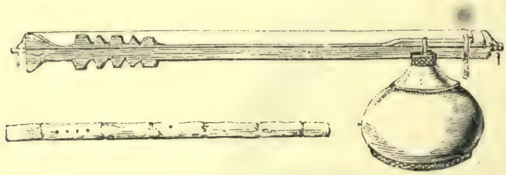


FIG. 101.—A violin of the Ouadjiji.

generally is impaired. This remedy, therefore, cannot be recommended for adoption. To the performer the "wolf" is always more or less of an obstacle, but one which, for all practical purposes, can be effectually surmounted by paying close attention first to the position of the "sound-post," which must be ascertained by experiment, and

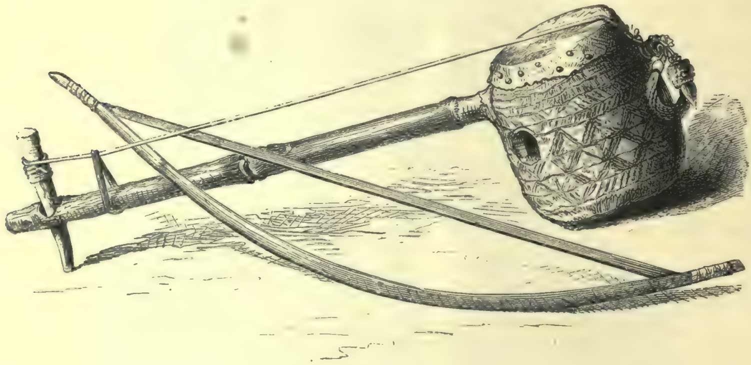


FIG. 102.—African violin.

secondly to the size of the string, since it will be found that the "wolf" increases in intensity in proportion to the thickness of the string. The "wolf" is found in all instruments of the violin family, but is most apparent in the violoncello.[1]

[1] The "wolf" occurs in its worst form in the wind-viol. When the string is *forced* to speak at the obstinate point, the instrument seems inclined to shake to pieces with the intense constrained vibration.

I think "wolf" might be generally defined as sympathetic "interference." I have

We shall only mention here modern stringed and bow instruments used in Europe. Formerly, the instruments of the violin family were more numerous and of great variety. Viols generally had six strings, bass-viols seven, and the *viola de Bardone* of the Italians had

FIG. 108.—Persian musicians. Violin and tambourine.

no less than forty-four strings, but evidently all these strings could not be touched by the bow. The greater number of these strings

tried intense string sounds upon a clean fir sound-board, and noticed how the dust was absolutely sucked in. Blackening the planks to their centre, this excessive action would amount to dislocation rather than displacement of fibre, and account for the fact which you justly notice.—J. B. H.

were of metal; they were tuned, some to unison and some to harmonize, and were resonant by sympathy or concurring motion. The *alto-viola* or *quint*, the *viola da gamba* or leg or *bass-viol*, and the *contra basso di viola*, or double-bass viol, are the only three types used in the present day, and are called the tenor, *violoncello* and *double-bass*.

We have thought it interesting to the reader to illustrate some types of instruments similar to the violin, taken from foreign countries. The Persian and Chinese violins do not appear to be constructed with greater art than those of the African savage tribes, or the violins of the Ouadjiji. They are very curious specimens of the infancy of the art, and of types with which the Amatis, Stradivariuses and Vuillaumes have nothing in common but the name.

§ IV.—The Guitar—The Harp.

The guitar and the harp are types of another class of stringed instruments. In these the vibrations are not produced by the friction of a bow, but by plucking with the fingers, or by striking with a piece of wood or quill; but, like instruments of the violin family, the notes of the strings are strengthened by a sounding box, the vibrations of the sides of which as well as the mass of contained air, heighten the effect.

In the guitar, the absence of the bridge, and the manner of vibrating the strings, causes the notes to be of much less power and sonorousness than those produced by bowed instruments. It also produces a very different tone, which gives to pieces played on the guitar a light, sweet and also a melancholy character. Moreover, this instrument is fitter for accompanying the voice than for solos.

The number of the strings varies. Each of them is struck or plucked, either on the open string, in which case it produces the fundamental note, or when shortened by the pressure of the fingers of the left hand, which press it on the frets arranged at convenient distances on the finger-board. The performer always plays correctly

[1] Persons interested in the history of instruments will find curious specimens of ancient instruments in the Museum of the Paris Conservatoire of Music, a collection which is constantly being enriched under the learned and zealous direction of M. Chouquet, the director.

if the instrument is in good tune, and always falsely if it is not, and from this point of view alone it is seen how inferior the guitar is to the violin. With the latter instrument, an artist with a good ear corrects the variations which are produced in the tension of the strings during the execution of a piece, by his fingering. In the guitar and instruments in which the notes are regulated by fixed frets, such a correction is impossible.

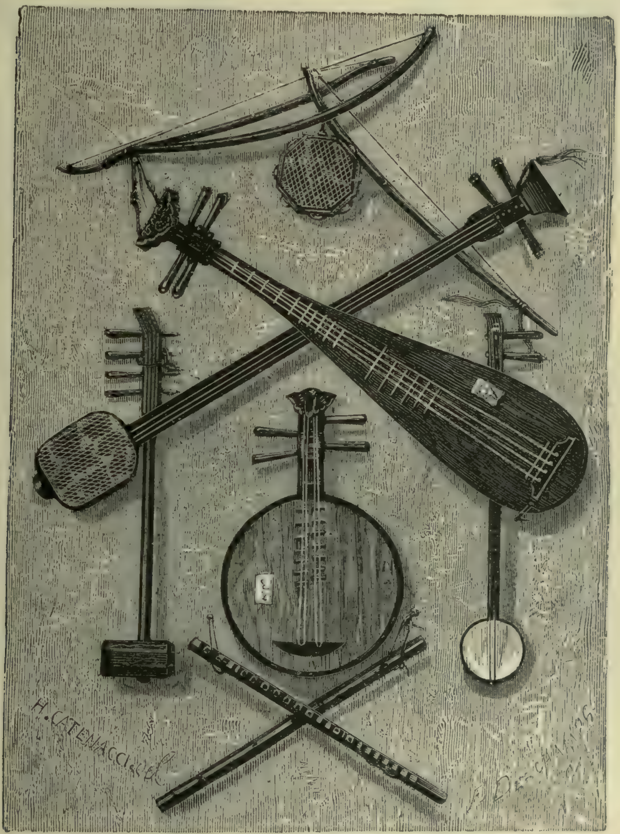


FIG. 104.—Chinese stringed and bow instruments.

The lute, arch-lute, theorbo, mandora and mandoline are of the same class of instrument as the guitar, but in the present day are nearly out of fashion. They only differ from the guitar in size, form of the sounding-box, number and material of the strings and the way in

which they are tuned. They are seldom or never used in orchestras; but the guitar and mandoline are frequently used by singers in southern countries.[1]

The harp, the antiquity of which is proved beyond doubt, is a stringed instrument put into vibration by the fingers. Its form differs

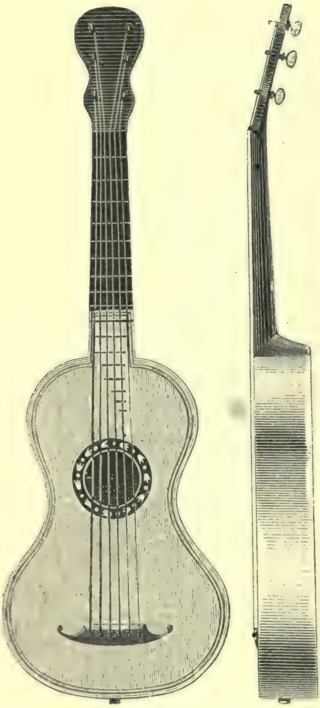


FIG. 105.—The guitar.

FIG. 106 —Theorbo, or arch-lute.

entirely from the violin, guitar or other instruments of these types. Although comparatively little used in the present day, it deserves a special description. The plucked string is almost the symbol of a pure and pleasing sound, owing to the great predominance given to

[1] "The origin of the guitar has never been determined. We have this instrument from the Spaniards, among whom it was really introduced by the Moors. The general opinion in Spain is that it is as ancient as the harp."—DIDEROT ET D'ALEMBERT'S *Encyclopædia.*—[Surely the Moors took it from the Egyptian "tampoura" ghitterncithera].

the fundamental, and probably its disuse is a sign of a taste vitiated by the mixed tones of modern chamber-instruments (harmoniums, &c.).

Formerly its construction was very simple; but it has been greatly improved in modern times. The harp is now composed of three parts, each of which corresponds to the three unequal sides of a triangle, as represented in Plate VII. The box, or sounding body, is composed of eight pieces of wood joined together, on which rests a plate of fir pierced with a certain number of sound-holes in the form of roses or clover. On this plate the strings are fixed by means of so many little buttons; at their other extremity the strings are fixed to the more or

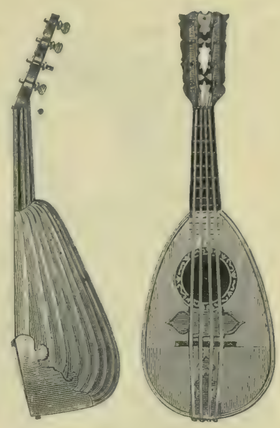


FIG. 107.—The mandoline.

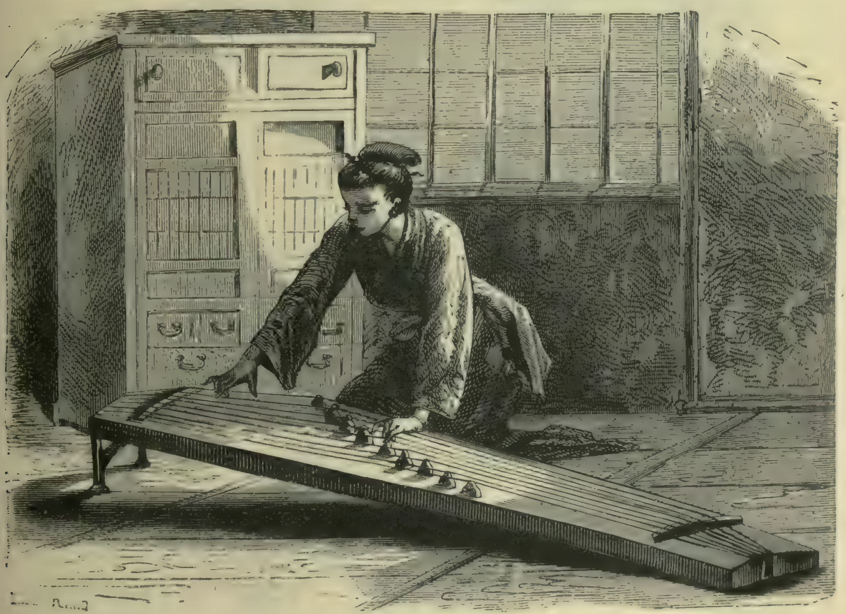


FIG. 108.—Japanese playing the gotto or "Taki Koto." [1]

less bent console, which constitutes the upper part of the triangle.

[1] To play the "Taki Koto," the performer fixes by little leather straps on the tips of each of her fore-fingers a piece of almond-shaped ivory—or split-almond flat

Then the strings are wound round pegs which enable the proper tension to be given them and the instrument to be tuned. In the lower part of the case, or at the foot of the harp, run out rods fixed in the third side of the triangle. Each rod is connected in the

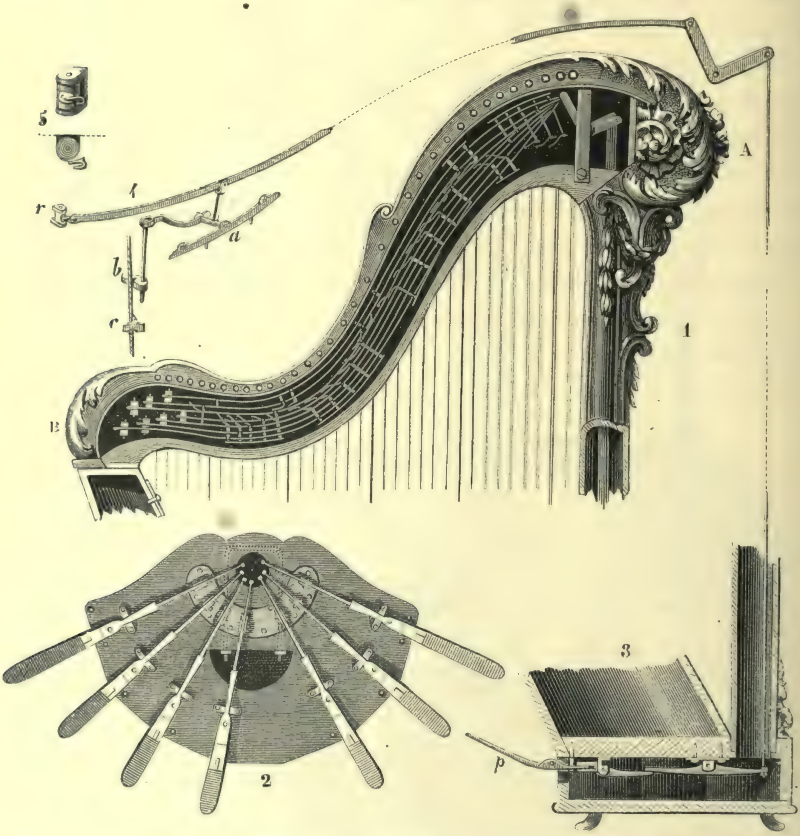


FIG. 109.—Mechanism of the harp. Key-board and pedals.

AB. Section of key-board, levers of the pedals, bolts and springs – 2. Pedals.—3. Mechanism of a pedal *p*; rod —4. *a*, arbor turning under the action of the pedal, causing the boot *b* of the hook to move, and resting the string on the nut *c*.—5. A spring serving to draw back the rods to their positions when the action of the pedal ceases.

foot, with a pedal which the performer presses when necessary to sharpen or flatten any particular note, as will be subsequently explained.

on the side, bound to the finger and rounded on the other—and these projecting an inch beyond the finger-tips she uses to pluck the strings, thirteen in number, made of silk or similar fibrous material. She arranges the bridges in a manner suitable to the music of her country and the relation of its tones.—H. S.

PLATE VII.—THE HARP.

At its other extremity, the rod is connected with a system of levers which, by means of mechanism in the console, press all the strings of the same name against nuts, which thus shorten them in the proportion required by the laws of vibrations of strings in order that each note may be sharpened throughout the instrument. The mechanism may easily be understood by the help of figure 109.

FIG. 110.—Welsh harp.

There are naturally seven pedals in the harp; three on the side of the left foot, used for sharpening the notes B, C, D, and four on the side of the right foot, to sharpen the notes E, F, G, A.[1]

[1] When the harp is played without pedals, the key is that of F (with one flat). The pedal B raising all the B♭ notes a minor second, makes them B natural, and the key then is C natural.

The performer on the harp places the instrument between the legs, the sounding-box resting at its upper extremity on the right shoulder, the strings and rods thus having a vertical position. He plucks the strings with both hands, the right being more particularly reserved for the upper notes, that is to say, for the shortest strings, the left hand playing the larger strings or bass notes. The compass of the harp is generally from four octaves and a half to five octaves, giving thirty-two or thirty-five strings from the B of the lowest strings (corresponding to the first B of the double bass) to A, which is in unison with the A open string of the violin. But in the present day harps have as many as forty-two and even forty-six strings, having as large

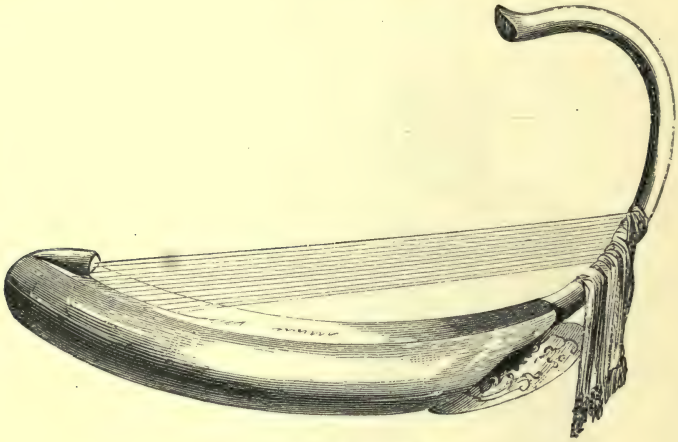


FIG. 111.—The Burmese harp.

a compass as that of pianos with six octaves. The beauty, purity, and brilliancy of the tones of this instrument causes its disuse to be regretted. The harp is now only as a rule found in the hands of strolling musicians, and talented harpists are rare. As the mandoline or guitar are the instruments preferred by southern countries, of Italy or Spain, so the harp is the national instrument of the northern countries, and especially of Ireland and Wales. The Welsh have a national instrument which they call the telyn. It is a harp with the peculiarity of having three rows of strings, the middle row corresponding to the black notes of the piano (sharps and flats). The telyn is played on the left shoulder and with the left hand. The Welsh harp is hence of a much more simple construction

than the usual form which we have described, the middle row of strings rendering the mechanism of the pedals, rods, and levers of the console useless; also the large number of strings makes the fingering more intricate. The Burmese harp represents the Eastern and Egyptian type which had no "pillar" to connect the framework; this was due not to ignorance but to design, a greater sympathetic resistance being thereby gained than would be imagined—through the "bow" action of the support.

§ V.—The Piano.

From stringed instruments, the vibrations of which are brought out by using the bow or touching with the fingers, we pass to those having strings which are struck by hammers, and put into motion

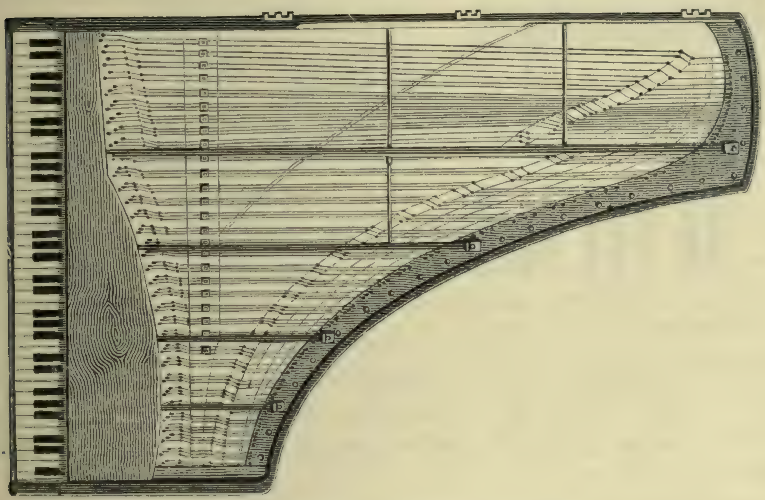


Fig. 112.—The piano; sounding-board and strings.

from a key-board. The piano, now so generally used, is one of these; and is *par excellence* a woman's instrument, being less fatiguing and more fertile in musical resource than the harp, but not superior to it in beauty of tone.

There are three important parts to consider in the piano; the sounding body or case, the strings, and the mechanism of the keys and hammers.

The case varies in form, according to the general arrangement of the instrument, which may be horizontal or vertical. This arrangement having nothing essential about it, we will confine ourselves to that which is prefered by piano players for the most favourable development of sound, and we will describe the one called a grand piano. In this the case has the form of a long triangle, similar to a harp, lying horizontally. The sounding case is of wood, generally oak, with a thin lining of fir, formed of several pieces glued and joined together; the sounding-board is for the same purpose in the piano as the upper plate, also made of fir, in the violin. It receives the first impression of the vibrations of the strings, and through its fibres these are communicated to the case of the piano, but particularly to the mass of air contained in it.

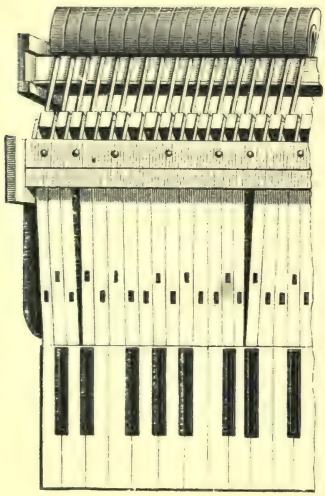


FIG. 113.—Piano: arrangement of keys and hammers.

Above the sounding-board and parallel with its plane, the strings are stretched on an iron frame-work strengthened with bars of the same metal, which give firmness and prevent the frame giving under the tension of the strings. These are of metal, their length and thickness being regulated according to the pitch and volume of the note required. Each note is represented by a double string for the low, and by a triple string for the middle and upper notes.

All the wires are of steel; but the lower ones have copper or silver wire wound round them. These combinations are conformable to the laws of the longitudinal vibrations of strings which teach us that the number of these vibrations, that is to say, the pitch of the note given by a string, is inversely proportional to its length, diameter, and tension.

The instrument is constructed in such a way that one of its elements, the tension of each string, is left to the free will of the tuner. By using an iron instrument or key, the tuner stretches each

of the strings in order to produce the series of notes of the diatonic and chromatic scale. This is generally done by means of comparison from one fifth to another, and requires great delicacy of ear, and a certain amount of skill, as temperament must be taken into account.

The necessity for temperament[1] in keyed instruments may be regarded as springing from the fact that the exact concords, viz., the octave, fifth, and major third, are intervals incommensurable in magnitude. In rigorously just intonation the constituent notes of a certain number of exact concords are provided, and consequently the proportion of available concords to the number of notes is small. Mr. Ellis's system of Duodenes is a method for dealing with just intonation of this type.

Temperaments of different kinds are systematic processes, in which these intervals are altered by small quantities so as to make them commensurable; let us employ an old rule as an illustration.—The interval of the major third is to the octave as the diameter of the circle to the circumference, very nearly. (Smith's *Harmonics*, Preface). But on ordinary keyed instruments three tempered major thirds make an octave exactly; consequently all the thirds are too large, just as three diameters would have to be stretched to make the circumference of a circle.

Again, the fifths of the ordinary key-board are too small by about $\frac{1}{50}$ of a semitone; tuners learn to estimate this by the ear with varying accuracy. The system thus obtained is called the *equal temperament*: it is now universally used; in it the octave is divided into 12 equal semitones. Four of these constitute a tempered major third, which is ·137 of a semitone sharp; seven equal semitones constitute a tempered fifth, about $\frac{1}{50}$ of a semitone flat.

There are many temperaments other than the equal temperament which possess historical and other interest. In all of these commensurable relations exist between the fifths, thirds, and octaves; but temperaments may be divided into two principal classes: non-cyclical, in which neither the fifths nor the thirds taken alone are commensurable with the octave; and cyclical, in which they are so. Of non-cyclical systems we may enumerate: (1) the Pythagorean system, in which everything is tuned by exact fifths, the thirds being sacrificed; (2) the mean tone system, in which the fifths are sacrificed to the thirds—this was Handel's system; (3) a system known as Helmholtz's

[1] For these remarks on temperament we are indebted to Mr. Bosanquet. [ED.]

system, or approximately just intonation. Of cyclical systems, the most important, besides the equal temperament, are the divisions of the octave into 53 and 31 equal intervals respectively.

Systems have to be divided into two classes in another way, viz., with respect to the nature of the relation between their fifths and thirds. Systems of the one class have properties analogous to those assumed in technical music, those of the other require treatment differing in many important respects; these latter present the more perfect concords, but the ♯ and ♭ notation becomes unmeaning with reference to them. Helmholtz's system and the system of 53 are of this latter class.

The sharp thirds of the equal temperament do not appear to offend ears accustomed only to them; and with soft qualities of tone they are but little offensive to any ears. But the stronger and sharper the tone the worse is the effect. The harmonium derives the greater part of its unpleasant character from the prominence which its peculiar tone gives to the effect of temperament. Instruments with sustained tones suffer more from temperament than percussion instruments, such as the piano. There can be no doubt that the equal temperament must be retained in practice so long as the ordinary key-board is employed, other key-boards have been proposed from time to time; and Mr. Bosanquet has constructed a "generalised keyboard," by means of which all temperaments can be dealt with in a complete form, within certain limits.[1]

Let us suppose the operation of temperament to have been accomplished; the piano is said to be tuned, and the whole series of successive strings are stretched so as to vibrate in unison with notes which compose the six or seven octaves of its key-board with their sharps and flats. Now how is each string or several strings put into vibration at once?

It is generally known that this is accomplished by placing the fingers of the two hands on the ivory and ebony keys arranged horizontally, and by holding them down for a certain time. But the mechanism by which this is actually accomplished is not so clearly

[1] For historical references on systems generally, see Ellis, *Proc. R. S.* 1864; and *App.* to Ellis's translation of *Helmholtz on the Sensations of Sound.* For the general treatment by Mr. Bosanquet, see *Proc. R. S.* 1875; and the article "Temperament" in Novello's *Dictionary of Musical Terms.*

understood, that is, what it is precisely which produces the sonorous vibrations, and stops or prolongs them at will; lessens or gives them their full power. It will be seen that this mechanism is really very simple.

Below the strings are arranged hammers *m*, *m*, *m*, (Fig. 114), which, when each key is at rest, remain side by side at a certain distance from the double or triple string which corresponds to each of them. By pressing down a key, that is to say, on lowering one arm of the lever which constitutes the arrangement, another arm is raised up; the corresponding hammer is sent sharply in the vertical direction, and strikes the corresponding string which then vibrates under the influence of the blow. We must now see how this movement of the hammer is effected, how it again falls after the shock without rebounding, and without making any noise. Fig. 114

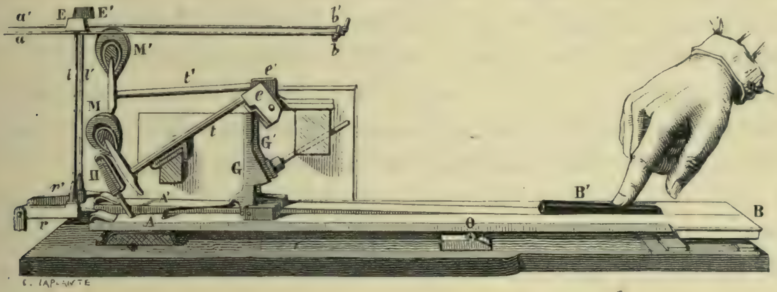


FIG. 114.—Piano: mechanism of the hammers and keys.

explains the entire mechanism to us. Let us follow the series of effects produced by the movement of pressing down the key.

ab is the string, AOB the key resting on the point O. On pressing B, the arm of the lever OA is raised, lifting an escapement G which strikes the extremity *e* of the handle *t* of the hammer. This hammer which is at first in the position M, then takes that of M′, and strikes the string which vibrates under the influence of the percussion. But the escapement after having raised the hammer a certain height, is itself stopped by a button placed obliquely; it frees itself from the head of the nut of the hammer which again resumes its first position on a small bridge H, which is called the chair. This prevents the hammer from rebounding, and deadens the noise that it would otherwise make in falling. Let us add that the strings which produce

each note, and which are struck together when the finger is placed on a key, would continue to sound after the blow, if they were not furnished with a small piece of wood covered with felt, called damper. As soon as the finger rests on a key, the damper E′ is raised, and the string vibrates; it remains up if the finger continues to press down the note; on the other hand it falls and cuts off the vibration, so soon as the finger leaves it.

We must next point out by what mechanism the pedals produce the increase and decrease of the intensity of the sound. One of them communicates by a lever with the whole system of dampers. When pressed down by the foot, a vertical rod is made to act on this system, and all the dampers are raised up at the same time; each note is therefore prolonged and gives a more intense sound; moreover, it communicates its own vibrations to other strings bearing harmonic relations of pitch to its own tone, so that the sonorousness of the instrument is considerably increased. If, on the contrary, the performer uses the other pedal, a slight movement from left to right is communicated to the key-board; each hammer then only strikes one or two of the three strings designed to produce the tone or sound, the intensity is thus diminished one or two-thirds.

The piano does not date further back than the second half of the eighteenth century. It is nothing more than an improved clavecin, an instrument first made in Italy, whence it has been imported to European countries. The clavecin often had several key-boards; but that which distinguished it from the modern piano, was the way in which the metallic strings were put into vibration. We have just seen that in the piano the percussion of a hammer causes them to sound; in the clavecin, or harpsichord, the keys move small pieces of wood called jacks, furnished with a crow-quill point. It is this point which plucks the strings. The notes of the harpsichord have not the same character or tone as those of the piano, they are thinner, and sharper, the tone is not so soft, and less sweet and intense.

The spinet was a kind of small harpsichord, with only one string to each note, and therefore only one row of jacks. This was in fact the primitive form of the harpsichord itself.

CHAPTER IV.

WIND INSTRUMENTS.

TO distinguish clearly musical instruments having their sounds produced by the vibrations of strings from those called Wind Instruments, we must not only consider the method of the production of sound, but also the nature of the body the vibrations of which determine the musical qualities of the sound produced, that is to say, its pitch, intensity, and tone.

We have seen that generally in stringed instruments the sounding body is not only composed of vibrating strings, arranged on a frame, but of a wooden or metal box or case, and the mass of air contained in it. Now the string alone, by its thickness, length, tension, and the substance of which it is formed, determines the musical pitch of the note and partly its tone. The body and the air which also enter into vibration when the string is struck, plucked, or bowed, serve to strengthen the sound produced, without modifying its pitch; they have also a great influence on the tone, by giving preponderance to one or another of the harmonics of the fundamental note; but they have no appreciable influence on the pitch.

In wind instruments which we are now about to describe, the sonorous body and vibrating mass is a column of air, with a form varying with that of the case in which it is inclosed; the variations of dimension and form of this column cause the variations in the musical pitch of the notes produced, and the sides of the tube only serve to modify the sonorousness or intensity of these notes. Solidity is the real desideratum in the walls of all pipes. The way to produce the note is therefore very different from that employed for stringed instruments. It is the column of air which must

be set in vibration, and this is accomplished by conveying a vibratory movement to one portion of it, generally at one of its extremities furnished with an appendage or mouthpiece which facilitates the setting up of this vibration. As a rule, it is by insufflation produced by the lips of the performer, or by mechanical means, that the vibrations are produced and communicated to the air contained in the instrument. Hence the name wind instrument.

These instruments are very varied in form, dimensions, and mechanism: some are constructed of wood, others of metal and even glass or crystal. But the most rational classification is that which distinguishes them by the special mouthpiece appropriate to each. We shall thus find musical instruments with flute mouthpieces: these are represented by the flute itself and the organ pipes, which were employed in studying the vibrations of gaseous columns in the *Forces of Nature;* then come instruments with beating or striking and free reeds; the clarionet and hautboy are the two principal types of this series: lastly, wind instruments with that kind of mouthpiece employed in the horn, trumpet, and most other brass instruments.

§ I.—INSTRUMENTS WITH FLUTE MOUTHPIECES—THE FLAGEOLET, FLUTE, AND FIFE.

Fig. 115 shows how the flute mouthpiece is formed, and how the vibrations of the column of air are produced by breathing or causing a current of air to pass over it. The breath or current of air produced by the bellows strikes against the bevelled sides, and divides into two currents, one of which acts on the interior column of air and puts it into vibration:[1] the vibration being the result of the successive compressions and reflexions of the strata of air on the edge of the bevelling.

We must not forget that if a vibratory movement is given to the column of air inclosed in pipes with a section small relatively to the length, the sounds produced will have a pitch inversely proportional

[1] Mr. Baillie Hamilton considers it doubtful whether the current is thus "split" on the top. He considers that it rather glances off externally, in a continuous stream, producing an aero-plastic "reed," in addition to its other functions of rarefying, &c.

to the lengths of the pipes. This is true with regard to closed pipes —those called the *bourdons* in the organ—as well as open pipes. Only in two pipes of the same length, the fundamental note in the open pipe is an octave higher than that produced by a closed one.

With the fundamental note, when increased intensity is given to the current of air, successive harmonic notes represented by the

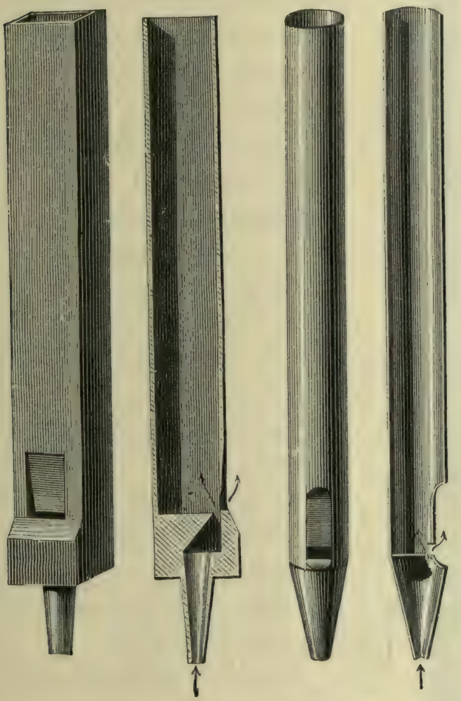


FIG. 115.—Organ pipes with flute mouthpiece.

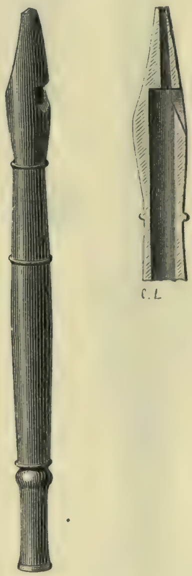


FIG. 116.— Flute-a-bec. Section of mouthpiece.

numbers 1, 2, 3, 4, etc., in open pipes, and the uneven harmonics, 1, 3, 5, in closed pipes, are also produced.

This statement of the laws is sufficient to enable us to understand the phenomena of musical acoustics produced in wind instruments, and the principles to be borne in mind in the construction of each of them. The form and the substance of which the pipes are formed, the mouthpiece and the way in which it is used, modify the tone, intensity, and sweetness of the sounds produced, not to mention

those qualities which depend in the greatest measure on the skill of the artist, which physics cannot analyze.

Whistles, flageolets, and fifes are the most simple instruments with flute-mouthpieces. In the first two, a pipe is fitted to the mouthpiece which exactly resembles those represented before, with the exception that the end is contrived so as to be placed conveniently between the lips of the performer.

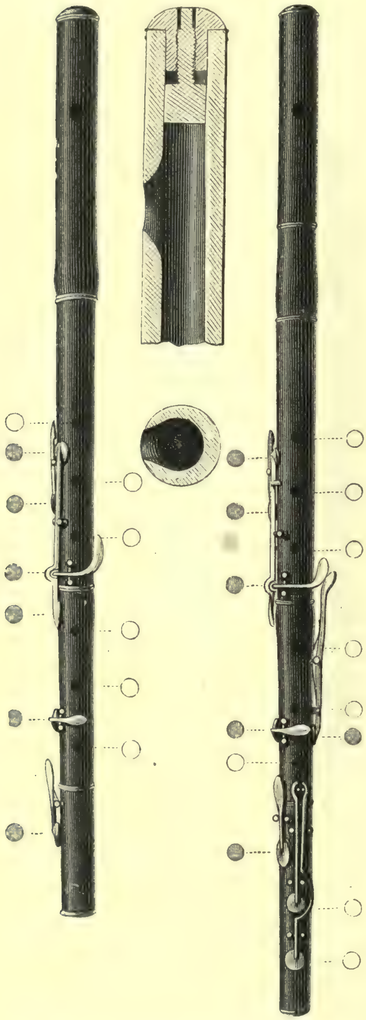


Fig. 117.—The flute. Longitudinal and transversal section of the mouthpiece.

The pipe is pierced with a certain number of holes made at points corresponding to the nodes of the interior column of air. When these holes are all closed by the fingers, the sound produced is the fundamental note, and its harmonics 2, 3, 4, that is to say, the upper octave, the third above this octave, and the double octave. By raising the fingers successively, the intermediate notes of the natural scale are obtained; the sharps and flats being produced by half uncovering the holes.

Flutes are made of wood, boxwood, or ebony, ivory and metal; the number of holes and of the keys which are used either to close or open them varying according to the instruments. Fig. 117 gives two specimens. In the last century, the flute called the German flute, to distinguish it from the flute with a beak, was much more simple: it had only seven holes, and its compass did not exceed two octaves. This is the ancestor of the modern flute.

In the flute and fife, the mouthpiece is an oval aperture, the edges of which are bevelled, and in front of which the lips, serving as air-conveyers, are placed. There is, moreover, this difference, that the current of air determining the vibrations has a transversal direction to that of the tube or pipe.

Fifes are small flutes with six holes, the sharp and lively notes of which relieve the performance of music. They are frequently used in military bands.

§ II.—Wind Instruments with Reeds—The Clarionet, Hautboy, and Bassoon.

Reed is the name given to an elastic plate arranged over the opening of pipes to receive the action of the current of air which is used in producing the sound.

This plate *a b* (Fig. 118) is adapted in front of the aperture of a hollow piece *c d*, either of wood or metal, which is called the *rigole*. The plate or tongue shuts the rigole when it falls exactly over its edges; when not pressed down it leaves a passage for the air and stands away from the edges in its normal position. Moreover, a metal rod *m*, with curved ends, may be pressed more or less on the tongue *t*, enabling the free portion to be increased or diminished. It is this free part which, in virtue of its elasticity, vibrates under the influence of the wind and communicates its vibratory movement to the column of air in the pipe.

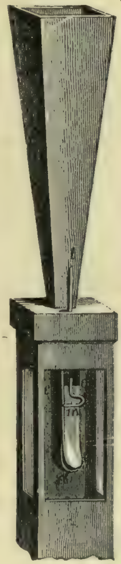


Fig. 118.
Striking reed.

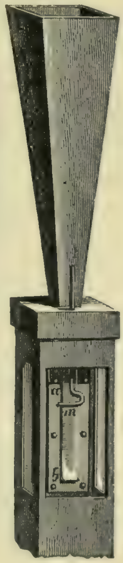


Fig. 119.
Free reed.

This kind of reed is called a striking reed.

In the free reed (Fig. 119) the tongue is fitted exactly on the aperture of a small prismatic box which communicates with the mouth

of the pipe. It is free to vibrate through this aperture, the vibration being of equal amplitude: this is the principal difference between a free reed and a beating one, its tones being harder and shriller.

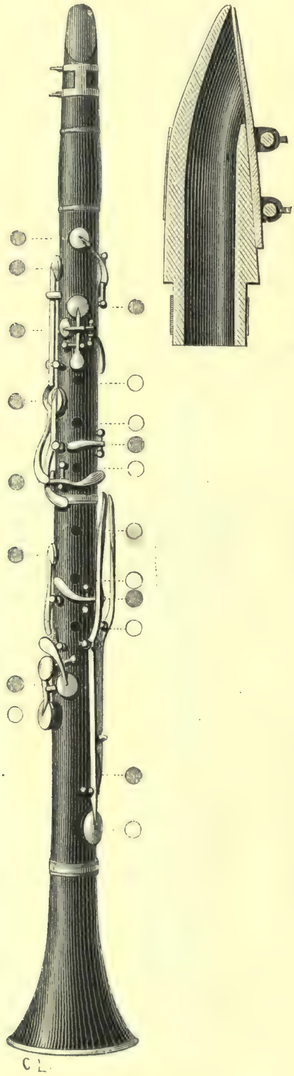


FIG. 120.—Clarionet.
Section of mouthpiece.

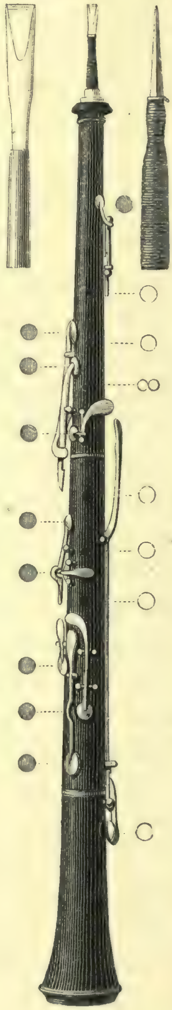


FIG. 121.—Hautboy.
Front and side view of reed.

What then produces the tone in the reed? It is not the vibrations of the metal substance which composes it, but those produced

by the periodical vibrations of the air. The number of vibrations, it is true, determines the pitch of the note. It is necessary, then, that the reeds adapted to a pipe be of proper dimensions and formed of a substance with a certain elasticity in order that its vibrations be isochronous with those of the column of air of the pipe. The curved wire also enables this result to be obtained. We shall see, when speaking of organ stops, how the notes produced are modified by the reeds, by adapting them to pipes of various forms which then are called *cornets d'harmonie*.

A word now on musical instruments sounded by means of reeds differing slightly from those adapted to organ pipes, but otherwise, vibrating in the same manner. First comes the clarionet, with the mouthpiece formed by a reed fitted to a pipe of box-wood, ebony or ivory, which the performer causes to vibrate by blowing into the narrow aperture which separates them. The performer's lips by pressing with more or less force against the two sides of the mouthpiece of the instrument, act as the curved wire and regulate the pitch of vibrations.

As in the flute, the intermediate notes of the diatonic and chromatic scales are obtained, by uncovering the holes successively or simultaneously, either by raising the fingers, or pressing on the keys or valves of the instrument. The pipe or body of the clarionet is terminated by a sort of bell, shown in Fig. 120.

The reed of the hautboy is formed of two thin layers of reed slightly carved in their cross sections, and placed one against the other, their edges and concavities facing each other; in the performer's mouth, they vibrate under the influence of the current of air produced by the breath, and the length of the vibrating part depends on the way in which the elastic plates are pressed by the lips.

The bassoon is the same kind of instrument as the hautboy but formed of pipes of much greater volume and producing notes two octaves lower in pitch than the hautboy. The bassoon therefore is to the hautboy what the violoncello is to the violin.

§ III.—Wind Instruments with Bell-shaped or Horn Mouthpieces.

In the musical instruments which remain for us to notice, the mouthpiece is simply formed of a tube, widened out in a conical form, or of a tube terminated by a hemispherical cavity which is placed against the lips (Fig. 122). In these instruments it is the vibration of the lips themselves which is communicated to the column of air inclosed in the differently shaped tubes which constitute the sounding body of the instrument. These vibrations can be produced more or less rapidly according as the performer presses the mouth against the aperture, and as the current of air passing through the lips is more or less narrowed. It requires great practice to calculate the dimension of this aperture, and the velocity and force of the current exactly to the pitch of the notes required—in short, to make the lips vibrate in unison with the fundamental note of the instrument, or with its harmonics. This is called using the lips.

Fig. 122.—Types of bell and horn mouthpieces.

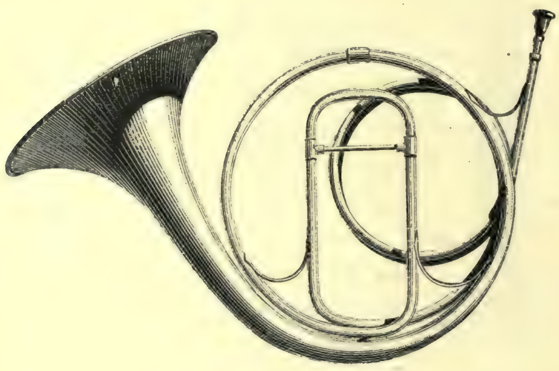


Fig. 123.—Cor d' harmonie.

The most typical of wind instruments with horn mouthpieces, is the horn itself, which is formed of a tube bent into a spiral form,

having a large bell-shaped end called the pavillon. Hunting horns, trumpets, and clarions are the same kind of instrument as the horn,

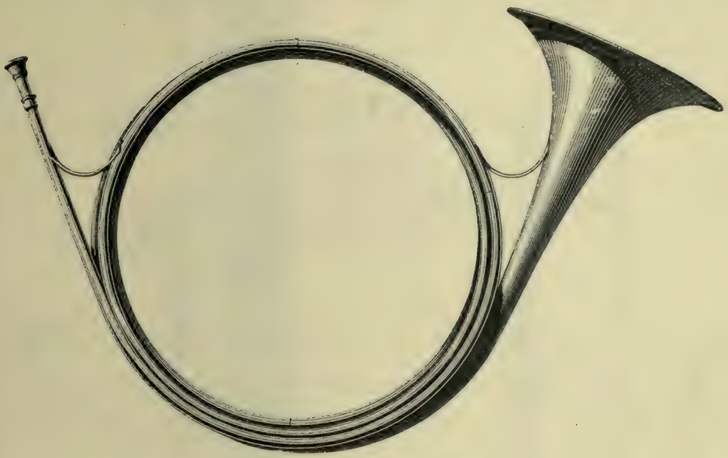


FIG. 124.—Hunting horn.

and all are generally made of brass, only differing from each other in

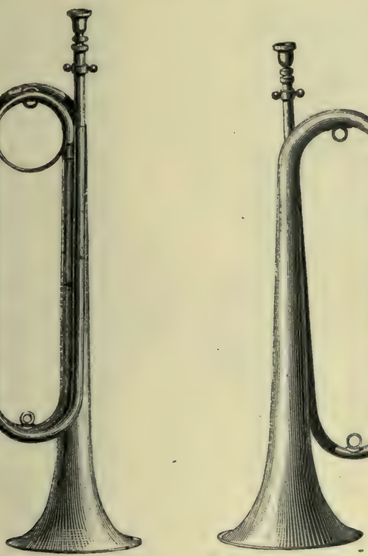


FIG. 125.—Trumpet and clarion.

the volume of the column of air, the shape, the tube, and lastly the dimension of the pavillon.

The notes which these instruments produce are the natural har-

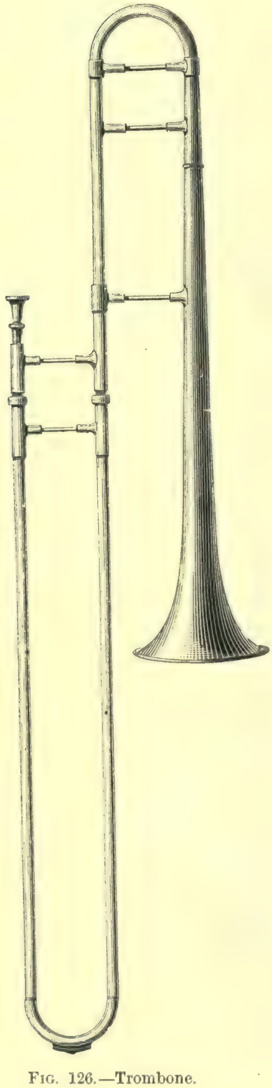


FIG. 126.—Trombone.

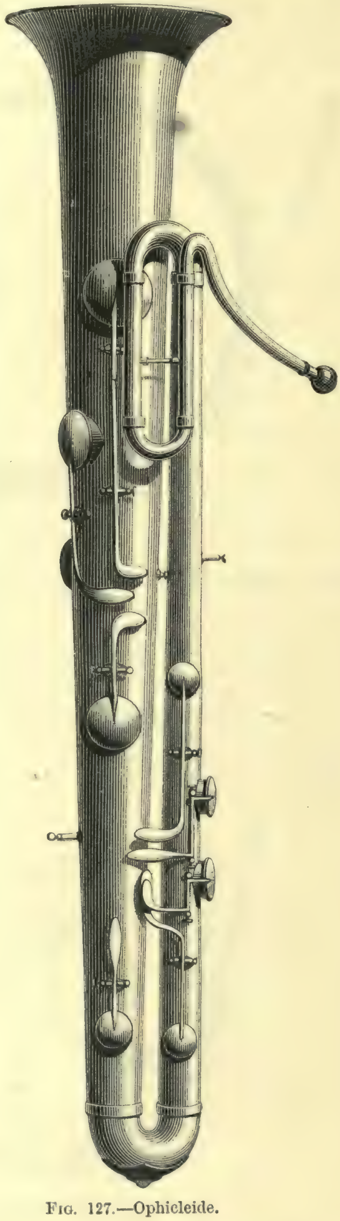


FIG. 127.—Ophicleide.

monics of its fundamental or deepest note; we have already stated how they are obtained. To get the intermediate notes of the scale, it

is necessary to stop up the aperture of the bell, in a more or less complete manner with the closed hand; it is difficult, however, to obtain in this way very just and pure notes. The stopping of the

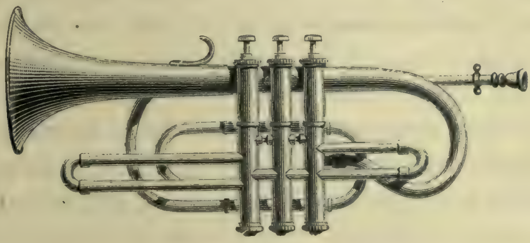


FIG. 128.—Cornet à piston.

aperture in the bell, takes away much of the brilliancy and sonorousness of the tones. The musical resources of brass instruments have been increased by modifying in different ways the length of the tube,

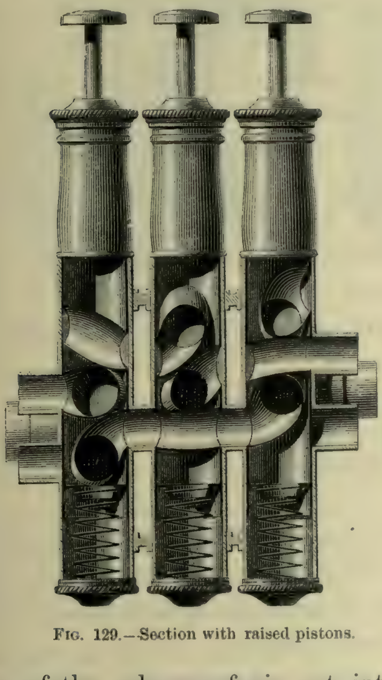


FIG. 129.—Section with raised pistons.

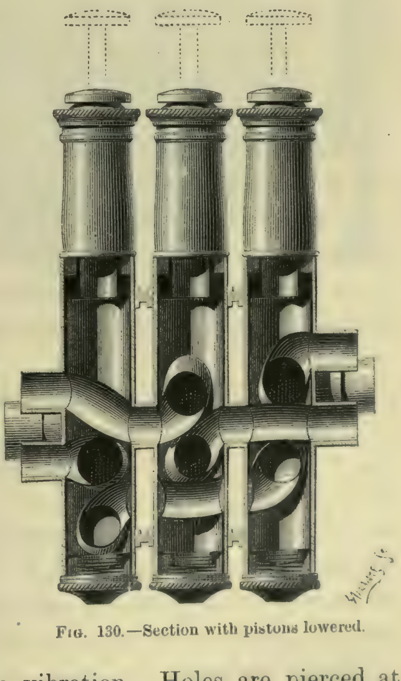


FIG. 130.—Section with pistons lowered.

or of the column of air put into vibration. Holes are pierced at convenient distances, furnished with keys, which open and close the metal sides of the instrument at will. The ophicleide is one of these.

the bass of all brass instruments, and all the family of instruments with keys, saxophones, so called after the maker who invented them, or at least improved the manufacture of them. Another modification is found in the trombone, a kind of sliding trumpet of ancient origin, formed of two parts encased one in the other, which the performer can draw out or in at will by a rectilinear movement of the right hand.

Lastly, a third method has been introduced in which the length of the column is varied by the introduction of pistons, as in the *cornet à pistons*, so well known in the present day in orchestras, and especially military orchestras. The pistons are nothing but portions of tubes, two or three in number, which are moved up and down in cylindrical parts communicating with the tube of the instrument. They are pierced laterally with apertures which correspond to appendages intended to increase the length of the vibrating column. According as the piston is lowered or raised, the apertures in question are placed in front of those of the appendages or in contact with the full portion; the communication is open or closed, as shown in Figs. 129 and 130, which represent a section of the cylinders holding the pistons, and of the pistons themselves. The performer presses sometimes on one, sometimes two, and sometimes on the three pistons. The appendages are themselves composed of movable pieces which can be lengthened or shortened to a certain degree. Lastly, the portion of the tube of the instruments on which the mouthpiece is fixed, can be more or less lengthened, according to the music to be played. In this way, the instruments can be tuned with all necessary exactness.

§ IV.—BAGPIPES.

All the wind-instruments we have already mentioned, whether the mouth-pieces are flute-, reed-, or bell-shaped, receive the current of air or wind which puts the column of air in the tube into vibration from the mouth or lips of the performer directly.

Before studying the organ, in which instrument the current is produced mechanically by bellows, we ought to say a few words about another kind of instrument in which the air which causes the

reeds to vibrate is inclosed in a skin with which the mouthpieces of the pipes communicate.

This is the bagpipe, which was known to the ancient Romans by the name of *tibia utricularis;* it is now only met with in a few remote districts of the French provinces, and in Scotland. The mechanism of the instrument will be easily understood from Fig. 131. A is the sheepskin used for the air-reservoir, which the musician fills by blowing into the wind-tube C; a valve inside is opened downwards and allows the air to enter, but not to escape. B, E, F, are three pipes, similar to flutes, or rather hautboys, open outside and furnished

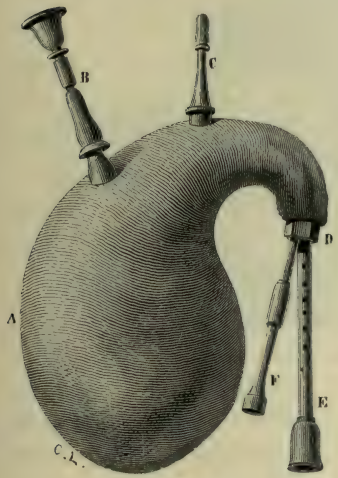


FIG. 131.—Bagpipes.

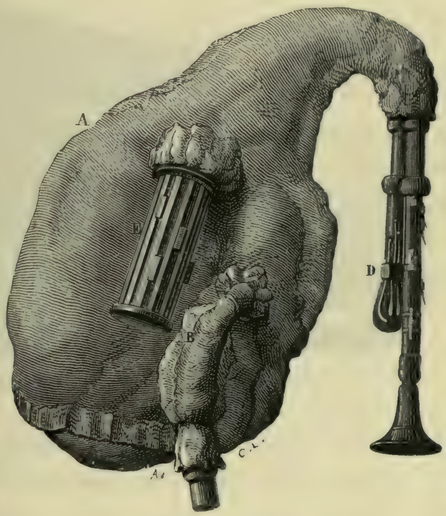


FIG. 132.—Musette.

at their other extremity inside, with reeds. B and F are called the great and little bourdon; they sound the octave to each other. The pipes E and F are pierced with holes which allow the notes intermediate between the fundamental notes and their harmonics to be obtained. When the musician has filled the bagpipes, which he holds between his side and left arm, he presses it with the elbow and thus forces the wind to escape by the reeds, which vibrate and cause the pipes to sound. By using the fingers the various notes may be brought out, and harmonies as well as melodies can be produced. It is possible to tune the pipes, as they are movable in their fittings, and can be lengthened or shortened to a certain extent.

The musette (Fig. 132) is an improved bagpipe, with the pipes C, D, furnished with keys like the instruments we have already noticed; the flute, hautboy, &c., and the bourdon E is a cylinder containing a series of pipes to which reeds are adapted inside. Some of these pipes are curved doubly, which gives deeper notes as their length is thereby increased. Slides which project outside, are movable along the length of the bourdon, and enable a slit which corresponds to the aperture of each pipe to be more or less closed. Another essential difference between this instrument and the bagpipe is, that the musician fills the instrument by the wind-tube B, not by

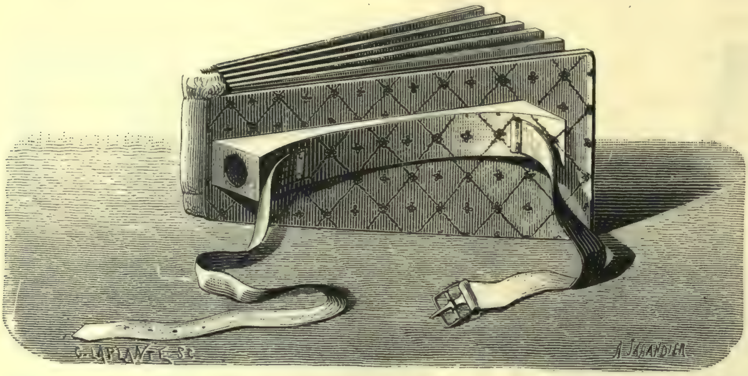


FIG. 133.—Bellows used to fill the musette.

blowing with the mouth but by working a bellows (Fig. 133) fixed to the opening of the wind-tube, and which the performer carries on his right hip.

The musette was the fashion in the 17th century, as much at the court and in towns as in the country; but, in spite of the originality and elegance of its form, and the profusion of ornaments with which it was decorated, it was already abandoned at the end of the reign of Louis the Fourteenth, by which time the taste for music was developed and improved. To day the musette is but a memory.

CHAPTER V.

THE ORGAN.

§ I.—HISTORICAL OUTLINE—PIPES AND STOPS OF THE ORGAN.

THE organ is the most powerful and complete, and the grandest of instruments. Its name indicates this (ὄργανον, in Greek, means, the instrument, the instrument *par excellence*) ; but, in fact, it is rather a combination of wind-instruments than one particular instrument. By its variety of tone, its voicing, and its compass from the deepest bass to the treble, it forms an orchestra in itself. The date of the invention of the organ is uncertain. Tradition carries it back to the eighth century, because it was in 757 that the first organ was introduced into the Christian Churches of the west. It is said, that this instrument was sent to Pepin the Little by the Greek Emperor Constantine, surnamed Copronymus, and it was placed in a church at Compiégne. But long before this period the Romans used an organ known as the hydraulic organ, because the movement of the air in the pipes was produced by the pressure of water. It was only in the 5th century that bellows were substituted for the primitive method, and that pneumatic organs took the place of hydraulic organs in churches; the damp, consequent on the use of water, rapidly changed and deteriorated the pipes and mechanism.

The organ is a wind instrument consisting of one or more series of pipes formed in wood or metal, either square, cylindrical, triangular or tapering, and with different-shaped apertures, and mouthpieces which the wind from the bellows, brought under control by means of finger-keys and the necessary mechanical appliances, puts into vibration either successively or simultaneously. We will describe

briefly, the various parts of the mechanism by which the organist obtains the musical effects peculiar to this wonderful instrument.

The purely instrumental or musical part of the organ comprehends an indefinite number of sonorous pipes which are grouped in series, according to their tones in the musical scale; each series constitutes a stop or register, and the different pipes which compose a stop are, as we shall see, distinguished by the pitch of the notes given out by the lowest of each series according to their scale and length when the wind from the bellows causes them to speak. Every organ-stop, correctly speaking, is one of individual tone, and may resemble any one of the particular instruments desired to be introduced into the composition of the piece of music to be executed. The organist can also use several stops at the same time by observing the laws of harmony, according either to his own inspirations or those of the composer whose work he is performing.

We will mention some organ-stops as they were constructed at the end of the last century, pointing out that, besides their particular names, others are given to them based on the maximum length of the pipe commencing each series and producing the deepest note. This length was expressed in feet. They are as follows:—

The double open diapason, of sixteen feet-tone, named in foreign organs *montre,* because its pipes were mounted or placed in the front of the organ case; the *bourdon,* a wooden-stopped pipe of sixteen feet tone, ranging from two to three octaves; the *bombarde* or double reed, sixteen feet of zinc, tin or wood, is a reed-stop, the preceding stops having flute mouthpieces.

The *diapason,* or foundation-stops of the organ are generally in metal of eight feet, and give the ground tone to the organ.

The twelfth gives a fifth above the principal.

The doublette or fifteenth is the octave above the principal (consequently two feet).

The larigot an octave above the twelfth.

Then come the stops, the cornet, furniture, trumpet, then the vox humana, cremona or clarionette, clarion and the voix celeste.

These different stops are formed of pipes with various mouthpieces, as we have already stated, and of various lengths—these lengths being calculated according to the laws of vibration in open or closed pipes—and further the forms also vary. Wooden pipes are square or

three-sided, or formed like truncated pyramids with square bases; pipes of tin or an alloy formed partly of lead and tin are either cylindrical or conical terminating in a point, or formed like a cone widened out as a bell. Figure 118 shows the form of the bourdon of sixteen feet and that of the double open diapason of sixteen feet. In

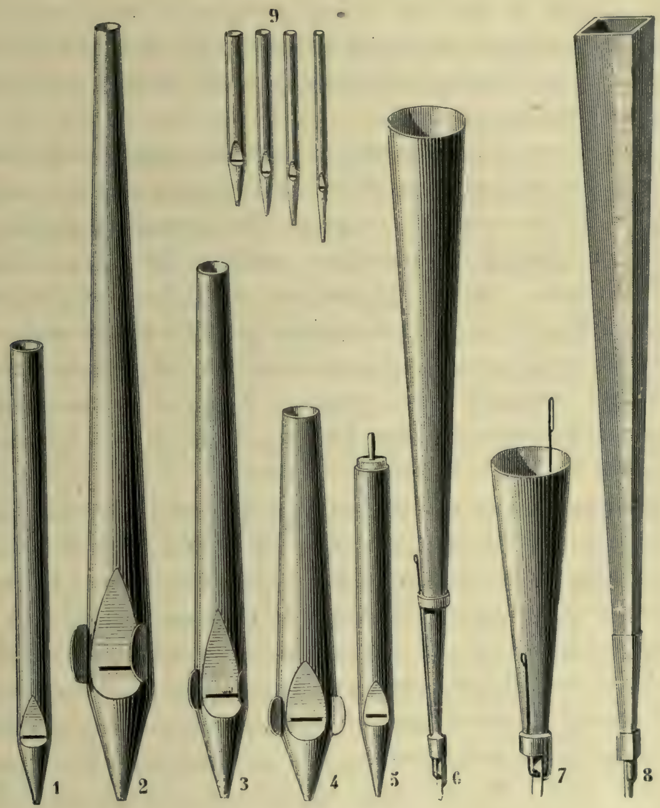


FIG. 134.—Organ stops.

1. Principal (4 feet).—2. Spitz-flöte (8 and 4 feet).—3. Twelfth (3 feet).—4. Cornet.—5. Flute (8 and 4 feet).—6. Trumpet (8 and 4 feet).—7. Vox humana (8 feet).—8. Bombarde, or double reed (16 and 8 feet).—9. Mixture (4 ranks).

Figure 134 may be seen the forms of the pipes of some of the stops just mentioned. There are open pipes, pipes quite closed, and lastly pipes with a chimney, that is to say, partially closed. Stopped wooden pipes are tuned by means of a wooden stopper covered with leather which closes the aperture at top: by raising or depressing this

more or less into the body of the pipe the length of the vibrating column is modified. Metal pipes were often tuned by using flexible metal plates soldered on each side of the mouth; these movable plates, called ears, could be pressed closer or pulled more open, and so flatten or raise the pitch of the pipe by influence on the freedom of the stream of air escaping at the mouth.

The system of ears for tuning purposes is now out of date. Lastly, the reed-pipes are tuned by using the tuning-wire to press the metal tongue against the aperture, and thereby to extend or shorten its vibrating length.

These stops as a rule extend to the same compass on the musical scale, or rather are composed of an equal number of pipes each producing one of the notes of the scale. For instance, beginning with the diapason which in modern organs embraces five octaves from CC to C in altissimo,—three high and two low; the principal, twelfth, fifteenth, flute, clarion and voix celeste have the same compass. All the cornets, grand cornet, and echo-cornet in all modern examples, each have a compass of five octaves. The vox humana, cremona, trumpet and bourdon give five octaves; the large open diapason and sixteen foot bourdon comprise five octaves.

The stops we have just spoken of belong to the organs built towards the end of the last century. By adding to them five pedal stops, we have thirty different stops to a complete organ. The number has been increased since. The organ at Haarlem, though now by no means approaching in size instruments of modern construction, is one of the most famous organs; it has 60 stops and 4,088 pipes. Many organs of more modern construction number considerably more stops, sometimes reaching 100 in number. The organs at Liverpool, Ulm, Saint Sulpice, Albert Hall, with other English instruments exceed 100 stops.

§ II.—Mechanism of the Organ—Bellows, Reservoirs, and Wind-Chest — Sound-Board and Table — Claviers, Key-Movement, Draw-Stops, Pedals — Combination-Pedals, Couplers, Swell Box, &c.

The instrumental or purely musical part of the organ being understood, it remains for us to point out the arrangement of the sonorous pipes; how and by what mechanism the performer makes them speak, either successively or simultaneously, in order to bring out the melodious and harmonic effects of the piece which he plays; and lastly how he uses any particular stop.

For more order and clearness, we will first describe the general construction and arrangement of an organ:—

The pipes of the different stops are arranged vertically in rows, side by side on rack-boards and inclosed with the necessary mechanical adjustments, in a wooden case more or less ornamented and of different dimensions according to the size and number of the pipes and registers.

Frequently when the organ is mounted on a screen or gallery the organ case is divided and has in front a small case called the chair or choir-organ, containing the registers mostly in use to accompany the voices. The great organ is at the back, the choir organ is in front, and between these two are situated the claviers or key-boards which place the instrument at the command of the organist.

Wind is given to the pipes by bellows blown by men, or any other motive power, such as water or steam. The air, more or less compressed, passes from the bellows through various channels or wind-trunks into the reservoirs and wind-chests, and from these into the grooves, boards, and pipes by the action of the pallets.

The wind-chest is a box, above which are arranged the pipes of the different stops. By pulling out the several draw-handles, placed conveniently for the hand of the organist, called stops or registers, the wind communicating with the pipes of the stop required is obtained, and on the performer pressing down the notes of the claviers, a mechanical movement, called the key-movement, acted upon by the pressure of the keys, opens the valves arranged underneath the

aperture of the pipes, which then give out the notes corresponding to the notes of the keys of the claviers so depressed.

In order to ensure steadiness of wind and speech in the pipes it is necessary, in organs of any pretensions, to divide the wind-chest, separating the wind of the lower or bass and tenor notes which demand a large supply, from the treble notes, which being of much smaller scale require much less wind. Each section of the wind-chest is supplied by its own wind-reservoir, and consequently an even and smooth tone is preserved throughout the entire register. Unsteadiness of wind is one of the most serious defects in an organ, the clearness of the articulation of the pipes being thereby destroyed.

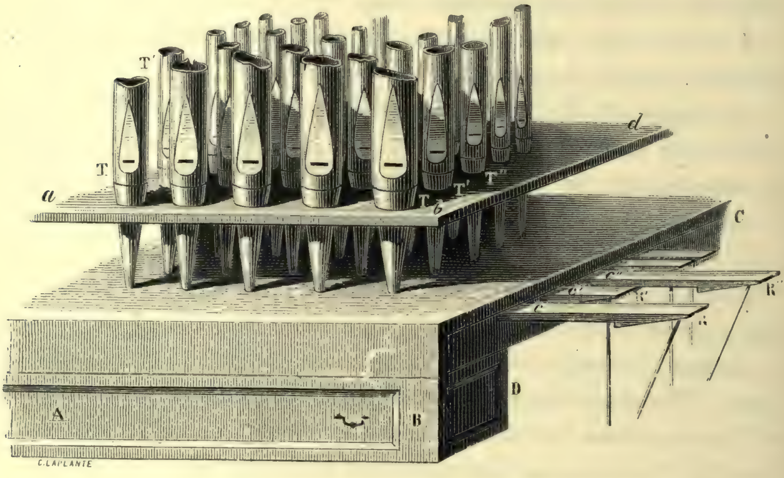


FIG. 135.—Wind chest furnished with its pipes.

Let us now notice each of the parts of the organ that we have just mentioned, in order that the reader may be able to form a clear idea of the working of the various mechanical details of this grand musical apparatus, justly termed the "king of instruments."

ABC (Fig. 135) is the sound-board. Several series of sonorous pipes, T,T,'T," are vertically arranged above the sound-board in parallel rows, each of which forms a stop, such as TT. The lower end of each pipe, termed the "foot," is planted on the sound-board. The wind is brought from the bellows by a wind-trunk to the interior of a sort of box or chest ABD, placed towards

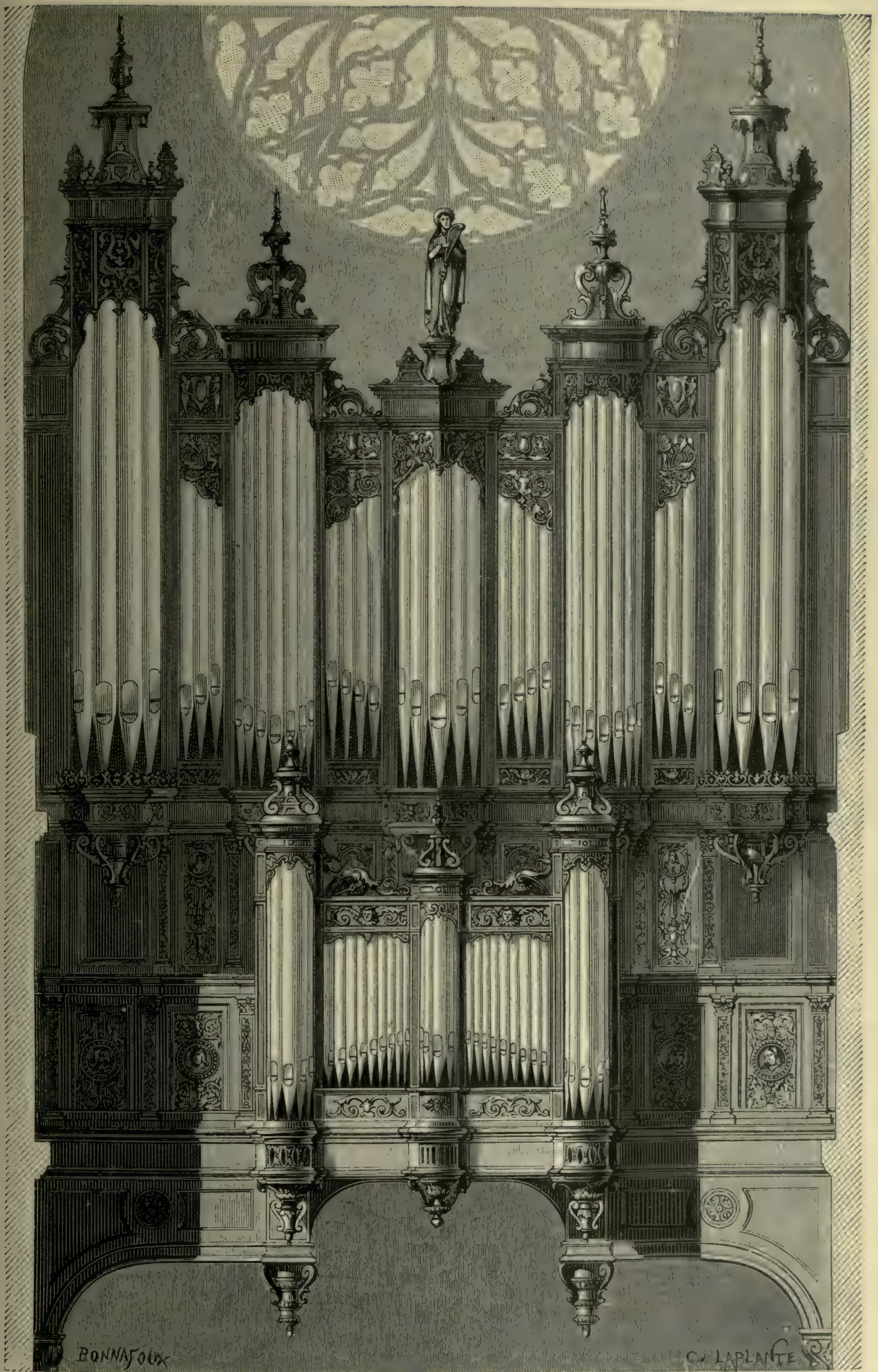


PLATE VIII.—ORGAN OF SAINT BRIEUC.

Constructed by Cavaillé-Coll.

the front and underneath the sound-board; this is called a wind-chest. We must now show how the wind can pass through this into the pipes above the sound-board. The upper board, besides being pierced with holes to receive the pipes, has also a series of grooves, each of which extends to the pipes of one key. These are separated from each other by parallel bars, called sound-board bars. Through these grooves holes are pierced vertically underneath the pipes of the stop. Lastly, a movable wooden slide, also pierced with holes, is made to pass through each groove; this is the stop or register, cR, c'R$'$, c''R$''$. . . . . Now, when the stop is open—that is to say, when the organist has drawn out the handle which corresponds to the stop he wishes to speak, all the holes of the stop are opposite to those of the table and the grooves which answer to the stop. The wind can then reach the aperture of each pipe. In this case it would cause all the pipes of the same stop to speak at the same time, if a special arrangement did not close the passage of the wind in all the pipes which did not precisely correspond to the note or notes which the performer pressed down. "To prevent this, the wind-entrances are first of all closed beneath by movable pieces of wood, s, (Fig. 136) which are kept close by the spring *r*, which, however, are so adjusted that any one or more of them can be drawn open at pleasure, by means of the 'pull-down' wire and lever action *d*, in connection with key-board and wind admitted into the corresponding groove. . . . These pieces of wood are called sound-board pallets; and from them the openings which they cover are named pallet-holes."[1]

The clavier of the organ is similar to that of the piano, with this difference, that the organ, according to size, possesses from one to four claviers. By pressing down a key with the finger, the organist puts into motion, with the assistance of a very simple mechanism called the key movement, the rods *d*, which open the valves, and thus bring the wind into the grooves of the wind-chest. Besides the keys worked by the hands of the performer, there are pedal claviers which correspond to particular stops, and which are put into motion by the feet. The pedals are exclusively for the bass.

In conclusion, let us imagine the organist seated in front of the

[1] *History of the Organ.* Hopkins and Rimbault.

claviers. The bellows are in action, and consequently the wind is in the wind-trunk at the proper pressure.

The organist begins by drawing out the stops he wishes to use on the several key-boards. These stops move a series of levers, which open the corresponding registers or stops.

That done, the pipe does not yet speak, although the wind-chests of the sound-boards are filled with wind ready to do the work wherever wanted. As soon as the organist places his finger on one of the notes of one of the claviers, immediately a valve (S) inside the wind-chest (AB) of a sound-board is opened, the wind penetrates into the corresponding groove, and thence into the pipes with the stops pulled out. The same thing happens if with his foot he presses down one or other of the pedals. From this moment the organ is at

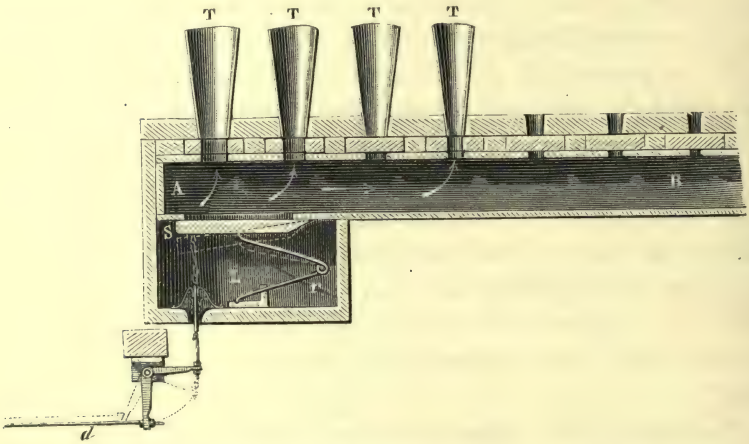


FIG. 136.—Transversal section of the sound-board.—Wind chest and valve.

work, and melodies as well as their harmonious accompaniments are produced at the will of the performer.

We have given the description of the organ and its mechanism as it was built at the end of the last century from D'Alembert and Diderot's great *Encyclopædia*, where it is described at great length. The reason of this is that many organs still existing are made after this model. But during the last century organ-builders have arrived at great perfection in detail corresponding to the progress of industry and art during this period. The mechanism of this wonderful

instrument has become more exact and sure, and it is increased in compass, power, and sonorousness. We can judge of this from some details relative to some newly-constructed organs.

In France the most remarkable are undoubtedly the organs of Saint Denis and those of Notre Dame, and Saint Sulpice in Paris. A French maker, whose name is generally associated with these magnificent instruments, is M. Cavaillé-Coll.[1] In England, the most remarkable instruments are those of St. George's Hall, Liverpool, by Willis, and the great organ, Primrose Hill, London, by Bryceson Brothers.

A word now on the bellows. We read the following in the official report on the inauguration of the great organ at Notre Dame :—

"The wind arrangement is composed of a large alimentary bellows, with double reservoir. This, with four pairs of pumps, can supply about 400 litres of air per second, and with the bellows at high pressure, having two pairs of pumps, will furnish 200 litres of air per second. Besides the four large regulator reservoirs placed in proximity with the wind-trunks which they feed, there are also in the interior of the organ two large regulator reservoirs at high pressure, four other regulator reservoirs for the echo, the large choir, and the trebles of the choir, clavier, and full organ ; a great number of air-receivers placed in different parts of the organ, and fitted with springs to avoid every kind of alteration in the pressure of the wind."

The utility of these various reservoirs, which do not contain less than 25,000 *litres* of compressed air, will be understood if we think that each pipe uses more than a *centilitre* of air per second, whilst the large thirty-two feet pipes each absorb 70 *litres* during the same time.

We have stated the simple mechanism which connects the movement of the keys of the clavier with the valves corresponding to a certain series of pipes. The fatigue due to resistance felt by the organist has been greatly alleviated by Barker's invention of the

[1] The following may be named as the principal makers who have contributed to the improvement of the organ. In France, Messrs. Cavaillé-Coll and Barker (an Englishman); in Germany, Messrs. Schultz, Töpfer, Walker, and the Abbé Vogler ; and in England, Messrs. Bishop, Hill, Gray, Willis, and Bryceson Brothers.

pneumatic action. This mechanism consists in the use of a puff-valve interposed between the key of the clavier and the valve before mentioned. This puff-valve is put into communication with the bellows by a wind-trunk, and a special valve, on which the key acts, fills itself, and exercises a sufficient power to overcome the resistance of the valve placed in the wind-chest, so that the force of the organist's finger no longer exerts itself on the valve with a wide surface, but on the small alimentary valve of the puff valve.

This principle is also applied to the working of the registers and the couplers, in order further to reduce the mechanical work of the performer.

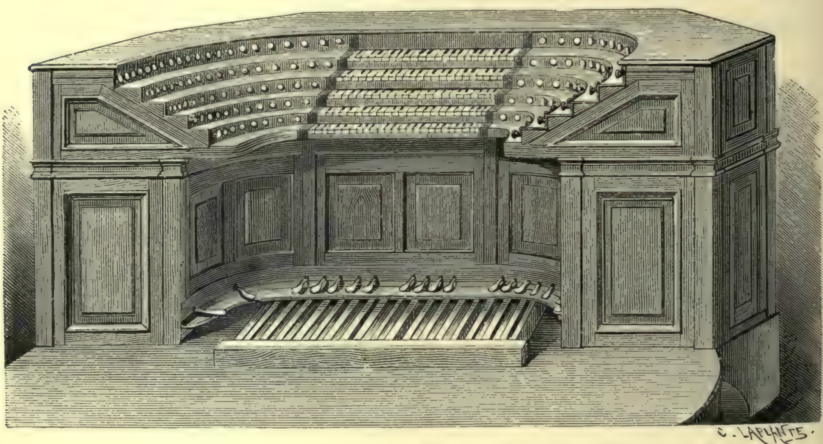


FIG. 137.– Claviers of the great organ of Notre Dame in Paris.

The number and variety of the stops have been also considerably increased in organs recently constructed.

The organ of Notre Dame possesses five manual claviers and one pedal clavier. The pedal clavier generally extends from C to F, and contains thirty notes; and in modern organs each of the manual claviers extends from C to C, five octaves, and possesses sixty-one notes.

Plate IX. represents the great organ, erected in a private music room at Primrose Hill, with its magnificent 32-feet speaking front, built by Bryceson Brothers; and as this instrument is one of the most modern and complete in its details and mechanism, a short description is appended.

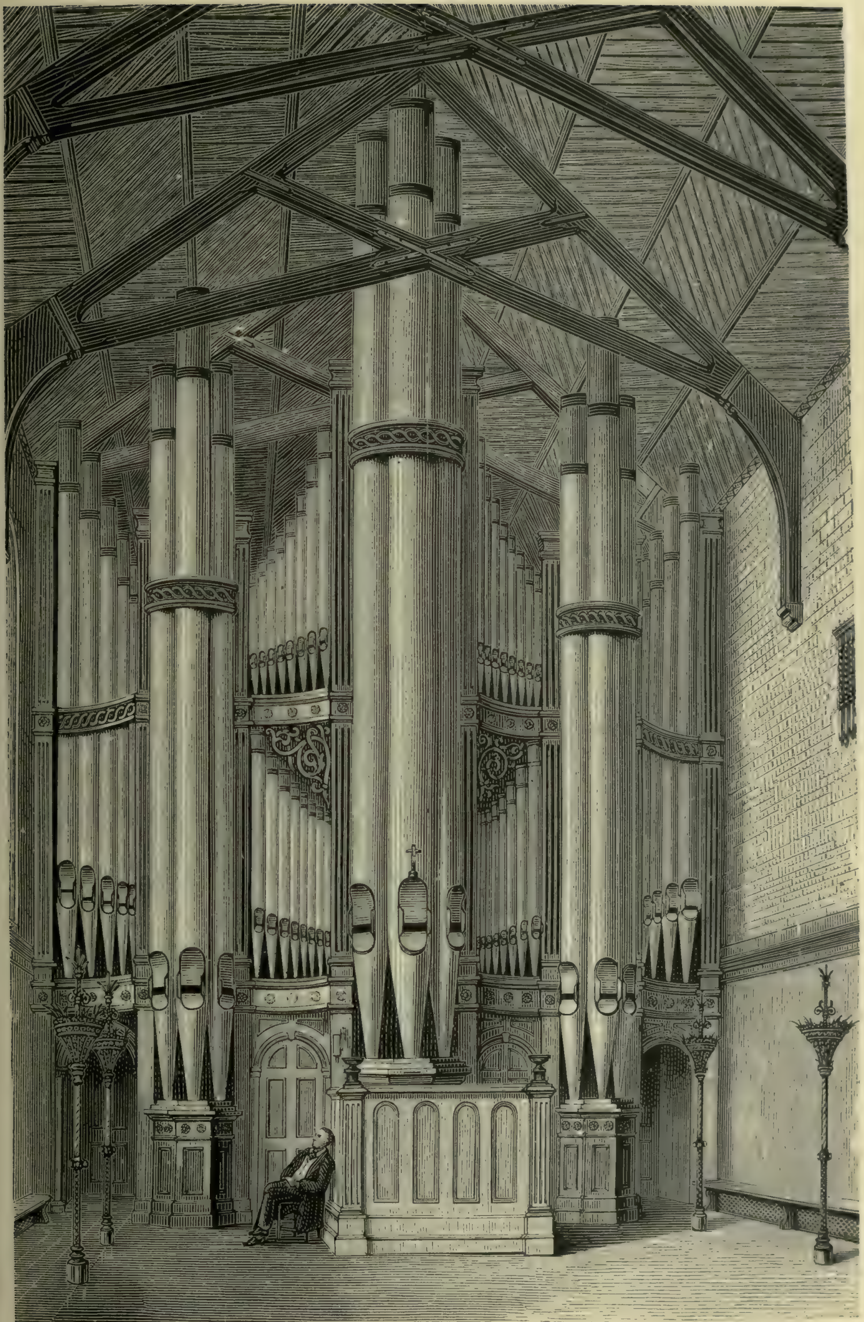


PLATE IX.—THE GREAT ORGAN, PRIMROSE HILL, LONDON.

Constructed by Bryceson Brothers.

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This instrument contains sixty-seven full speaking stops and thirty-one mechanical combinations, in all ninety-eight tone-controlling movements, and embraces seven distinct organs, namely,—

Pedal organ	30 notes
Great organ	61 notes
Choir organ	61 notes
Swell organ	61 notes
Solo organ	61 notes
Echo organ	61 notes
Carillon organ (Metal Bells, 4 feet.) . . .	61 notes

The motor power which gives wind to this important instrument is an eleven-horse steam-engine, which sets in motion "vertical feeders," for the double purpose of supplying wind at different pressures into special reservoirs, whence it is distributed by a series of wind-trunks into seventeen other reservoirs in connection with the various organs and sound-boards, and also of creating a vacuum in two large vacuum reservoirs, which, by means of a series of independent conveyances, distribute throughout the interior of the instrument the "vacuum pressure" for performing all the mechanical action of the organ—namely, drawing the stops and couplers, vacuum pneumatic key action, pedal action, echo action (100 feet distant from key-boards), and carillon action. The great advantage of atmospheric vacuum over compressed air as a motor is, that the one is instantaneous—"nature abhors a vacuum"—while, from the elasticity of air, the other is slow and uncertain. The vacuum pressure is distributed by means of metal tubes, which ramify from the console in connection with the registers, combination foot-pedals, and combination finger-buttons, couplers, and tremulant action, over the entire instrument, to independent power bellows in connection with the various sliders, &c. By this means the mechanical action of the organ is brought under the control of the performer at the key-boards, who has at command the various changes of registers and "tone colouring" of the entire instrument. The "echo organ," an independent instrument, placed at an elevation of thirty feet, and at a distance of 100 feet from the great organ keys, is actuated by electrical agency, and the mechanical action by "vacuum pressure." Thus the connection between the two organs is simply "vacuum

tubes" and insulated metallic conductors (sixty-one in number), which convey the electric current to the several pallets of the wind-chest. The great organ at Primrose Hill, London, therefore, affords the most perfect example of the "composite" organ, partly mechanical and partly electrical. Without the important aid of electricity, it would not be possible to place mechanically an echo organ so

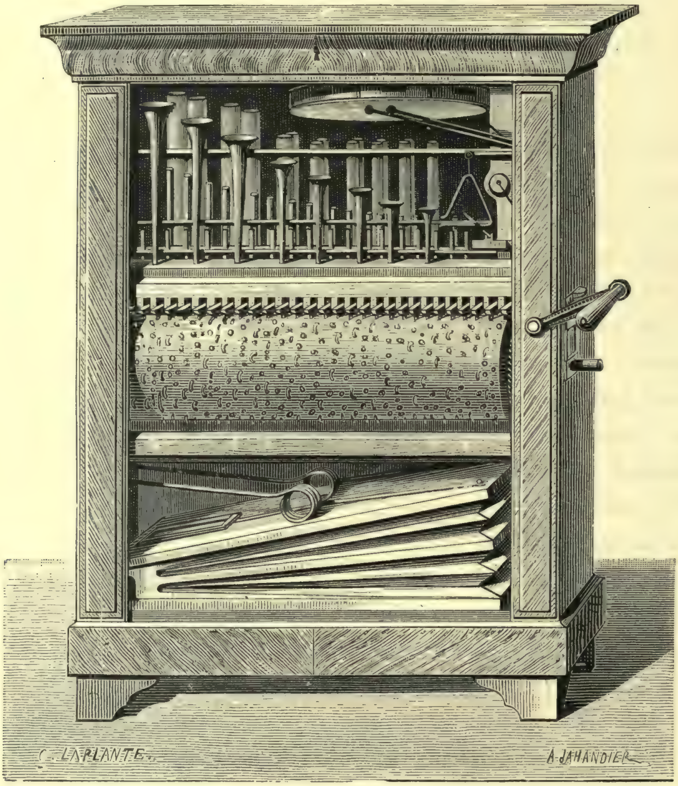


FIG. 138.—Barbari's organ, commonly called the Barbary organ.

distant from the key-board. The large thirty-two-feet pedal pipes and the thirty-two-feet bombard are severally supplied with wind by independent pneumatic exhaust pallets, insuring promptness and fulness of speech.

In this organ, which may be taken as the example of modern mechanical appliances, the French system of ventils has been abandoned as being unsuitable to the exigencies of the performer upon an

instrument of such gigantic proportions, and the ventil system of bringing on or shutting off an entire family or group of registers has given place to the vacuum pneumatic composition pedals acted upon by the feet, which arrange the "tone colour" of the foundation and mutation stops and accessory finger key-buttons by which the performer is enabled to see his registers and comprehend his combinations, a most important matter when it is remembered that, in instruments of the first magnitude, the attention of the performer is more or less absorbed between the difficulties attendant upon mechanical changes and the musical rendering of the piece.

We may conclude our description of wind instruments with a short reference to the cylinder organ known under the popular name of the Barbary organ (it should be Barbari organ, and not Barbary. Barbari is really the name of the maker in Modena who invented this automatic instrument). By turning a handle, a cylinder, furnished with "pins" of various lengths, is rotated, which causes the keys of a clavier to move. Corresponding to those keys is a mechanism which sets a series of stops in action, the pipes of which put into vibration by the air of a bellows, speak, and can thus reproduce a piece of music.

Besides the small barrel-organs we see carried about the streets, others of much greater dimensions have been made. Fig. 138 represents one of these. They are doubtless of no great value with regard to perfect tone, and the music they play is not always very agreeable to the ear of *dilettanti*, but they serve to popularize in country and town the most beautiful airs, overtures, marches from operas, and symphonies. On this account they certainly deserve to be mentioned.

BOOK III.

APPLICATIONS OF THE PHENOMENA AND THE LAWS OF LIGHT.

BOOK III.

APPLICATIONS OF THE PHENOMENA AND THE LAWS OF LIGHT.

CHAPTER I.

MIRRORS AND REFLECTING INSTRUMENTS.

§ I.—MIRRORS OF POLISHED METAL—SILVERED MIRRORS—REFLECTORS.

THE use of mirrors is very ancient. Without going back to the time of Moses, and the book of Exodus which refers to the mirrors of the women who stood at the door of the tabernacle, metal mirrors were in use among the ancient Egyptians (Fig. 139). In Greece and Rome, people decorated the walls of their rooms with polished and reflecting plates of steel, silver, gold, and obsidian; it appears too, if one may judge by different passages in Pliny and Aristotle, that glass mirrors lined with a sheet of polished metal were not unknown.

But it was not until the fifteenth century that we find silvered plates of glass substituted for polished metal. In the present day we know how universally they are used either for the toilet or for interior or exterior ornamentation. Although glass mirrors are inconveniently breakable, they are still greatly superior to metal ones, as they do not get dim, whilst the former rapidly oxidize and tarnish and thus require careful keeping in order.

In the present day, manufacturers of looking-glasses can produce them of enormous size and with such delicacy of polish that it equals the beauty of the transparent substance itself. The whiter and more

colourless this substance is, the more perfect is the mirror, because then the luminous rays which have to travel twice through it to return to the eye after being reflected by the polished surface of the quicksilver, are unchanged in tint and only very slightly weakened by this double transmission.

One word now on the reflecting surface of silvered mirrors—this surface, which is not of glass, but a thin sheet of tin amalgam (that is, a mixture of tin and mercury), is placed at the back of the glass in the following manner. On a very smooth stone table, sur-

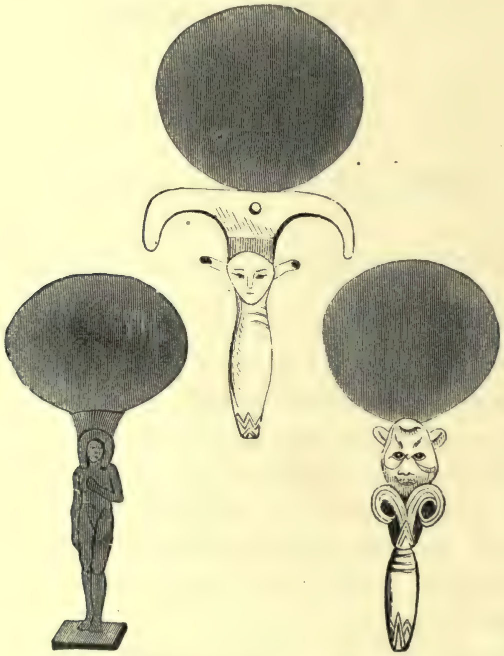


FIG. 139.—Mirrors of the ancient Egyptians.

rounded by a gutter, the sheet of tin is spread out, and is then covered with mercury. The glass, well cleaned, is then passed over the stratum of mercury in such a manner as to clear off the surplus liquid metal; then with the help of weights the adhesion of the glass to the amalgam is effected. The process of coating with mercury is injurious to the health of the workpeople, and silvering has been tried, which is produced by pouring on the surface of the glass a composition of nitrate of silver, ammonia and tartaric acid.

Silver, as well as tin, has a considerable reflecting power, but the tint of the image is slightly yellowish.

In Belgium and many other northern countries, mirrors having a movable joint are placed outside the windows of houses and arranged in such a way as to enable what is passing outside to be seen in the interior of the room. These mirrors are also used by shopkeepers to watch their goods, and are known by the name of "spies."

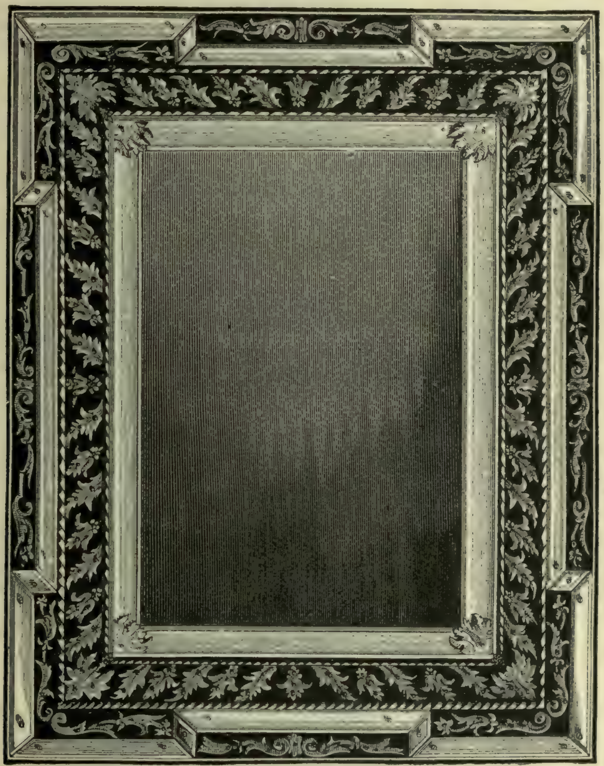


FIG. 140.—Venetian mirror.

Large silvered or metal mirrors are also used to reflect light from the sky to the interior of a room, which would otherwise be dark. These reflectors are frequently employed in dark and narrow streets in London and other large towns.

Before describing the scientific instruments based on the phenomenon of reflection from the surface of plane mirrors, we may

mention an easy and interesting application of the laws of reflection. Its object is to measure the height of objects such as trees, houses, edifices, etc. A small plane mirror (Fig. 143) is placed on the ground in a horizontal position between the eye and the object to be measured. Then, on drawing further away in the direction of the line which connects the base of the object and the mirror, the image A′ of the

FIG. 141.—Window mirror, or *espion.*

summit A is seen. It is easy to understand that at this moment the ratio of the height of the eye above the plane b to the height of the top A of the tree is exactly that of the horizontal distance bO to the horizontal distance of the foot of the tree at O. An easy calculation then gives the required height.

In the *Forces of Nature* we have described various ingenious appli-

cations, amusing or useful, of reflection by plane mirrors combined with each other in different ways: this class includes the magic

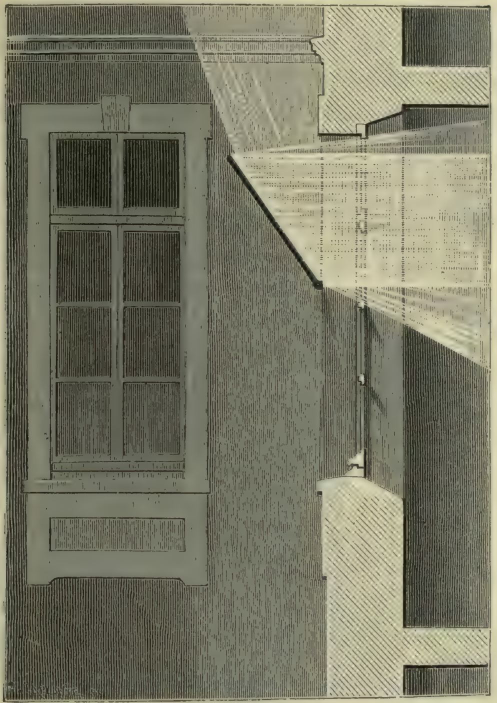


FIG. 142.—Street Reflectors.

telescope and mirrors, the polemoscope and kaleidoscope; for these applications, therefore, we must refer the reader to that work.

FIG. 143.—Measuring the vertical height of an object.

§ II.—The Sextant.

The instrument we are about to describe was formerly called an octant or reflecting quadrant. It is used by sailors to take the heights of stars or the angular distances of the moon from the stars—called "lunar distances."

The invention is due to Hadley (1731); but several scientific men including Newton, Hooke, Thomas Godfrey of Philadelphia, and Harris, had thought of a similar instrument, based on the same principle. Hadley was the first who made it, and who proved its great practical utility.

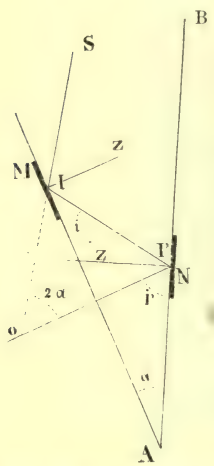


Fig. 144. — Theoretical principle of the sextant.

The sextant is an application of a very simple geometrical principle, which is itself an immediate consequence of the laws of reflection. It is as follows :—

When a ray of light, before it reaches the eye, has undergone two successive reflections on two plane mirrors, the angle of deviation of this ray is exactly double the angle of the two mirrors.

Suppose SI (Fig. 144) a ray coming from a light source, a star for instance; it falls at I on the mirror M, is reflected towards I′ and falls on the second mirror N; there it is reflected a second time, takes a new direction I′O and reaches the eye. The angle SOI′ formed by the incidental ray and the second reflected ray is double the angle a formed by the two mirrors.[1]

The following is a description of the sextant as it is now made.

It is composed of a circular sector, with a graduated arc measuring about 60° (hence its name sextant; formerly an arc of only 45°, or the eighth of the circumference, was used and the instrument was

[1] The demonstration of this proposition is very simple : the angle at O is equal to the difference of the angles SII′ and II′O, that is to say to $2(90°—i)—2(90—i')$ $= 2(i'—i)$. On the other hand, the angle a is equal to the difference of the angles II′B and I′IA, that is $= i' — i$. The angle of the two mirrors is therefore half the angle of deviation.

therefore called octant): the one represented in figure 145 consists of 85°. At the centre of the sector is fixed an arm furnished with a movable index and a vernier V, which enables the fractions of a degree on the arc to be read: *l* is a small microscope used for this purpose. A silvered mirror M is fixed normally at the centre of the sector and in the line of the zero of the movable index. It is movable with this index. A second mirror M′ is fixed on one of the sides of the sector so that when the two mirrors are exactly parallel the reading vernier is at the zero of the graduation: this second mirror is only silvered on its lower half.

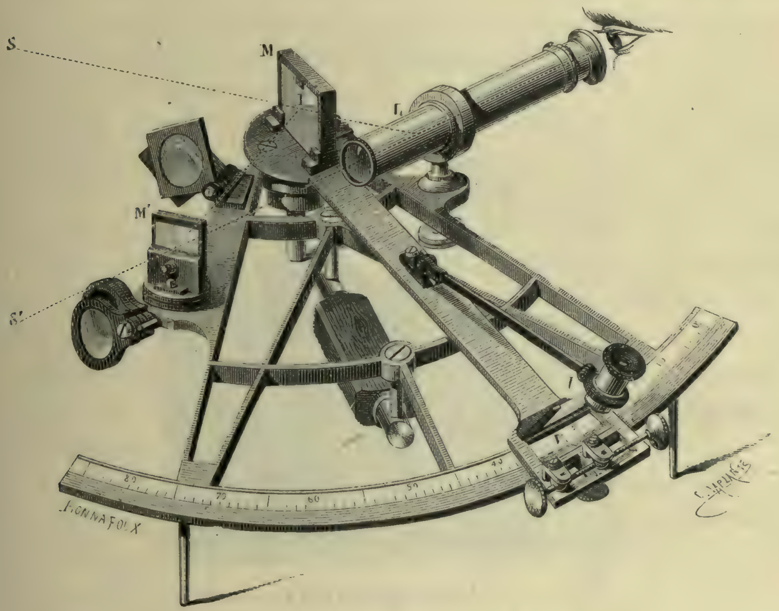


FIG. 145.—The sextant.

Looking through a telescope L fixed on the opposite radius of the sector to that on which the fixed mirror is placed, a point situated in the direction LS′, can be seen directly as half the mirror M′, is transparent, and by reflection, another luminous point reflected doubly from I on the first mirror, and I′ on the second, can be seen when a perfect coincidence of these two images has been brought about. It is clear that the angle formed by the rays SI, S′I′, is double the angle of the two mirrors for the reason already stated. Now, the angle of the

two mirrors is that between the movable index and the zero of the sextant.

The way in which this instrument is used will be now easily understood.

The observer takes it by the handle with the left hand; then, putting the eye to the eye-piece of the telescope, he sights one of the objects, a star for instance, through the unsilvered portion of the small mirror. He then moves the sextant until the other star is in the plane of the sector; afterwards turning the index and the large mirror, he brings the image of the second star, after two successive reflections, into

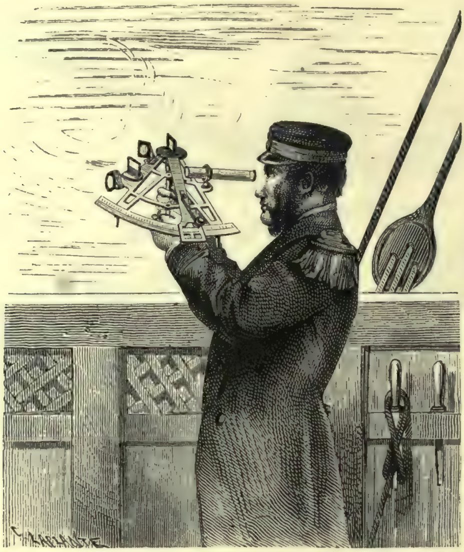


FIG. 146.—Naval officer observing with a sextant.

coincidence with that of the first, in the centre of the field of the telescope.

When the angular distance from a star to the moon has to be measured, the star is sighted directly and the image of the edge of the luminous disc is brought in contact with the image of the star. If the angular distance between the sun and the moon has to be determined, the image of the sun is brought in contact with the lunar image; but in this case coloured glasses are placed before the large mirror to reduce the intensity of the sun's rays.

If the distance of a star above the horizon, called its altitude, is to be measured, the sextant is held vertically, so that the star is in its plane, and the horizon formed by the surface of the sea is sighted directly with the telescope. If this horizon is undefined, an artificial one is used, either a mercury bath, or a polished glass rendered horizontal by three levelling screws and a level.

§ III.—GONIOMETERS.

It is known that in nature there exists a great number of bodies which have a definite geometrical form, most often marked by plane and polished sides or faces grouped in various ways. Such are crystals. Mineralogists who find crystals ready formed in the rocks, and chemists who obtain them by various methods, both take equal care to define their shapes and to mark with precision the angles of each of their faces. They accomplish this by the help of instruments called goniometers (from *γωνία*, angle and *μέτρον*, measure), which are also based on the principles of reflection. Very often, indeed, the faces of the crystals are so far reflecting that each of them may be considered and employed as a plane mirror.

Reflection goniometers are of various forms. We will confine ourselves to the description of the two most used, Wollaston's and Babinet's goniometers.

Wollaston's goniometer is composed of the two following parts:—

1. D is a vertical disk divided into degrees on its edge and movable on a horizontal axis, which may be turned by means of a milled head, G. A vernier V fixed to the support of the instrument serves to indicate the angle through which the limb has been turned.

2. The axis of the limb is hollow; a rod passes through it, which by using another milled head, A, can be rotated independently of the graduated circle. This rod supports a jointed arm and this again has a metal plate, capable of turning in different directions by means of a handle and joints. The crystal is placed on this plate and its angle measured, as follows.

Choice is made of two horizontal parallel sights, for instance, the edge of a roof of a house and a bar of a ground floor window; or again, an upper sight is secured by the top of an open window, the dark

line of which stands out against the sky, and for the lower one the edge of a table or of a sheet of paper placed on it.

That done, the goniometer is placed in such a position that the limb is exactly vertical (a level and feet with screws enable this result to be obtained), and at the same time in a direction perpendicular to the sights chosen. Afterwards the crystal is fixed on the plate of the instrument by means of wax; and it is necessary to place it in such a way that the edge of the angle to be measured be itself perpendicular to the limb or parallel to the axis of rotation.

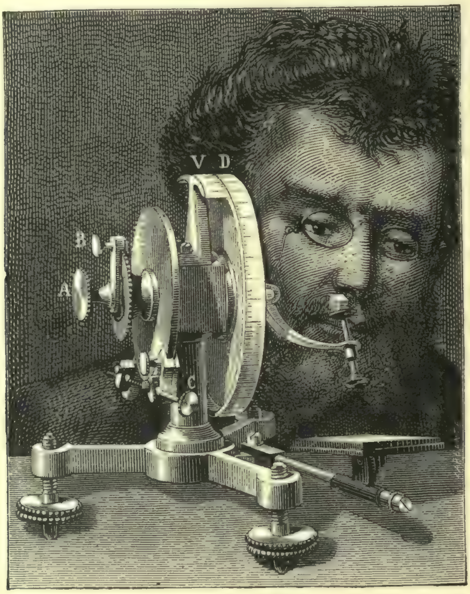


FIG. 147.—Wollaston's reflection goniometer.

To secure this, images of the two sights obtained by reflection on both faces are used, images which, for each of the faces, ought to be parallel between themselves.

When these preliminary arrangements are once taken, the zero of the limb is placed in coincidence with the zero of the vernier. Then turning the crystal by means of the milled head A, the image of the upper sight as seen in the first face is brought into coincidence with the lower sight, seen directly. Then the limb is turned, and consequently the crystal, until the same coincidence is obtained, this time

by the second face of the crystal. This latter has then taken the two positions indicated by the figure, and each face has turned through the angle a (Fig. 148).

The reading of the angle of rotation of the limb gives in degrees and fractions of degrees, not the angle β of the crystal itself, but its geometrical supplement, a, from which the first is deduced by a simple calculation.

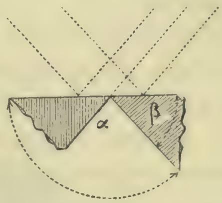


FIG. 148.—Geometric principle of the goniometer: rotatory angle of the crystal.

Babinet's goniometer consists of a horizontal graduated limb, carrying a collimator always fixed on a radius of the circle. This is a telescope having in the focus of its eye-piece two crossed threads. A second movable telescope with an index and vernier turns round the centre, or may be fixed in any position by means of a clamping screw. Lastly, a platform placed at the centre of the circle, is made to turn on a vertical axis, and is furnished with an index and vernier which serve to measure the angle of rotation. On this platform the crystal is placed, taking care to have the edge of the angle to be measured vertical.

Let us now see how the angle is measured.

First, the movable telescope is fixed in a position which makes a certain angle with that of the collimator; the zero of the index vernier is brought opposite the zero of the graduated arc, and the stand on which the crystal rests is turned until the micrometer-thread in the eye-piece is made to coincide with the image of the micrometer-wire of the collimator seen by reflection by one of the faces of the crystal.

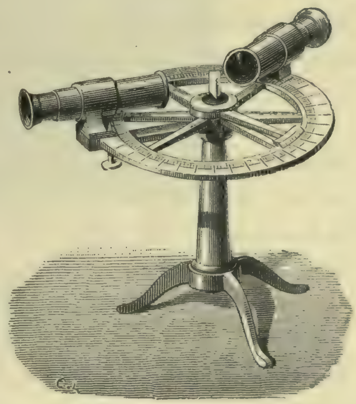


FIG. 149.—Babinet's reflection goniometer.

Now, the crystal is again turned, but this time by the aid of the arm attached to the platform, until the same coincidence takes place by a reflection from another surface.

The angle of rotation measured by the movable arm is that of the normals to the reflecting surfaces, so that by calculating the

supplement of this angle we have that of the two faces of the crystal.

Fig. 149 shows one of Babinet's goniometers mounted on a tripod stand, but smaller ones are made which may be held in the hand. The same instruments may be used in optical researches when prisms are employed, the angles of which require to be known with accuracy.

§ IV.—The Heliostat and Siderostat.

In many optical experiments, it is necessary to project, in a constant direction for some time a beam of solar light, which, without certain precautions, the diurnal motion of the sun would render impossible. If the beam is first received on a plane mirror, whence it is again sent back, by reflection, towards the point or towards the object to be lighted up, the inclination of the mirror must constantly change in order to give a constant direction to the reflected beam.

This is accomplished by means of an arrangement which was described when speaking of the solar microscope (*Forces of Nature*). This consists of a mirror capable of turning at will round two axes, one horizontal the other vertical if the reflected beam itself takes a horizontal direction. But the assistance of the observer is always necessary to regulate the orientation of the mirror in a proper direction.

Heliostats are instruments intended to give this assistance; the mirror which forms the reflecting portion is put into continuous motion by clockwork, and a suitable mechanism keeps it at such an inclination that the solar rays, reflected on its surface, take a constant direction, in spite of the diurnal movement of that body.

There are heliostats of various kinds dating from the time of s'Gravesande, but we will mention those only named from their inventors, Silbermann and Foucault. But in the first place, we will point out the principles common to all, without which neither their arrangements nor the working of their mechanism can be well understood.

The line PP′ (Fig. 150) representing the axis of the earth—the invariable line around which the diurnal movement of the stars and sun takes place, the circle S will be the apparent path traversed by this

latter body in a day, the angle S O P being the polar distance of the sun at the time under consideration. At A, is an equatorial dial on which the shadow of the style AO marks the hour every instant of the day. The line SOB then indicates the path followed by a solar beam, and if we imagine that the line OB turns round the point O constantly following the extremity B of the ray AB, it will be the path of the incident light during the whole day.

Suppose RR the direction in which the solar rays are required to be constantly reflected, the bi-sectrix NN′ of the angle S OR will be normal to the point of incidence, this determines the position the

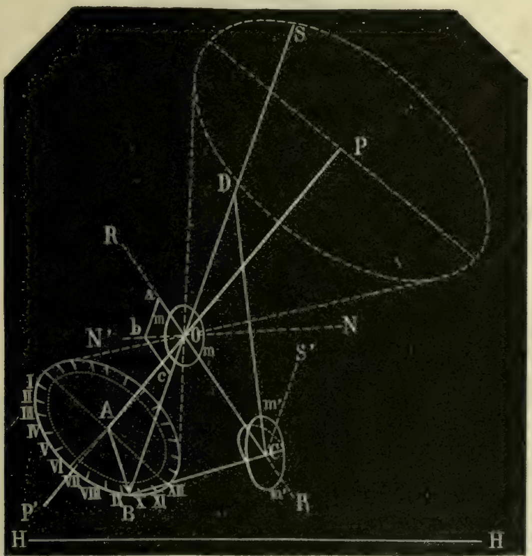


FIG. 150.—Geometric principle of the various systems of heliostats.

mirror *mm* ought to occupy at the supposed moment, in order that the reflection be made in the desired direction.

The whole question is, then, to keep the mirror in a position relatively always the same with respect to the constant direction of the reflected ray and to the variable direction of the incident ray. This may be accomplished in many ways.

1st. Underneath the equatorial dial is placed a clock, which moves a needle AB and causes it to describe an entire circle in twenty-four hours. This needle is then always placed in the direction which would be exactly occupied by the shadow of the style. At its

extremity a rod BO is fixed to which an inclination is given with regard to the dial, equal to the declination of the sun for the day of observation. This is the first condition which all the various systems of heliostats have to fulfil.

2nd. The rod OB carries the mirror; and it is connected with an articulated parallelogram, O*abc*, the diagonal of which, O*b*, coincides

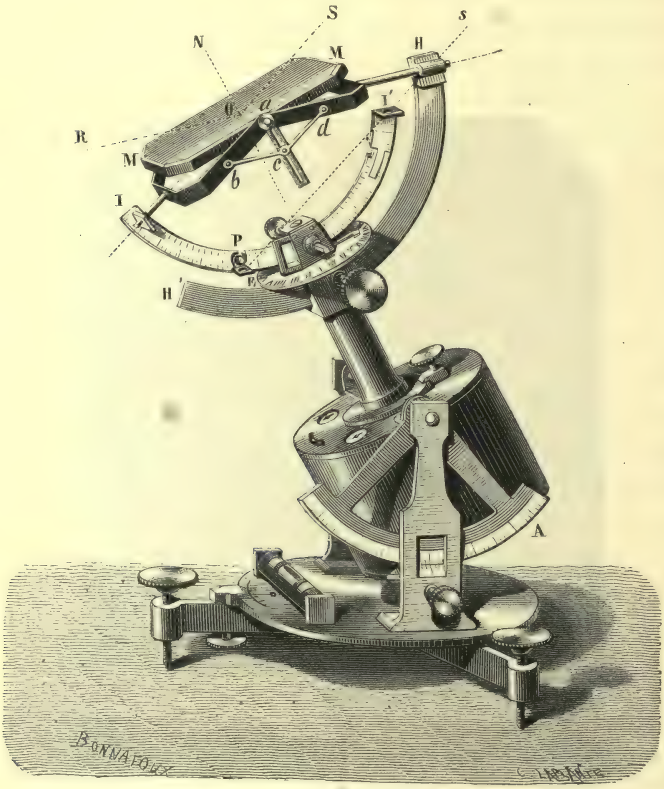


FIG. 151.—J. T. Silbermann's heliostat.

with the bi-sectrix of the angle SOR, that is to say with the normal to the point of incidence, the fixed side O*a*, of the parallelogram following the direction OR given to the reflected beam. Such is the arrangement of the heliostat devised by J. T. Silbermann, and which is shown in Figure 151.

3rd. Suppose now, OC, a rod of constant length, taking any position

round the point O, or that wished to be given to the reflected ray. This rod is hollow and carries a fork to which is fixed the mirror, $m'm'$, which can also turn round OR and BC. Another rod CD, arranged in the plane of the mirror, is joined to a ring at D, at the extremity of a rod OD equal to OC. A ray S′C, which falls on the mirror parallel to SO will be reflected in the direction CR. This is the arrangement of Gambey's heliostat.

4th. The mirror is supported at C by an upright, on which it can

FIG. 152.—Foucault's heliostat.

be moved in every direction. It is regulated by another rod CB, normal to its surface, and connected at B to a ring fixed on OB at a distance OB = OC. In its plane a third rod CD has a slot, in which the prolongation OD of OB can slide. The two triangles, OCD and OBC, are always isosceles, so that the normal to the mirror CB is parallel with ON, the bisectrix of the angle of the incident and reflected rays. This is the principle of Foucault's heliostat.

These principles explained, it is easy to understand the mechanism of the three systems of heliostats—those of Gambey, Silbermann, and Foucault's. The last two are represented in Figures 151 and 152.

§ V.—The Siderostat.

A serious inconvenience in instruments used in observatories for researches in physical astronomy is, that the observer must move with the eye-piece of the telescope according to the part of the heavens he wishes to study, and to the motion of diurnal rotation which displaces it. He is therefore subjected to very inconvenient, annoying, and fatiguing positions, which are detrimental to the study of the phenomenon observed. When observations have to be made with the transit telescope or theodolite a rectangular prism may be used, at the back surface of which the luminous rays undergo total reflection, and send the images in a constant direction. The instrument to which this modification is applied is called a *broken telescope*. But this is a solution which is not applicable to equatorials, where the axis is moved uniformly with the axis of the earth, and follows the star observed, as the diurnal movement causes it to change its place. To remedy this, and to avoid the inconveniences referred to, Léon Foucault constructed the instrument which has received the name of Siderostat, the idea of which was first thrown out by Hooke. This is nothing more than a telescope, with its optical axis invariably fixed in a horizontal position, into which the image of the portion of the heavens to be observed is reflected by a mirror moved by clockwork, exactly regulated to the diurnal motion. A large part of the heavens can thus, at the will of the observer, pass before the telescope, which remains immovable; and the observer, without any discomfort, keeps his eye to the eye-piece of the instrument. The siderostat is, then, to begin with, really a kind of heliostat, in which the direction of the reflected ray remains constant and horizontal.

Fig. 153 shows its arrangement very clearly. The mirror turns on a horizontal axis, and is kept in position by two vertical supports moving at will on a system of rollers round a vertical axis. With it

is connected a rod normal to its surface, which slides in a ring fixed to a fork, the axis of which bisects the direction of the incident and reflected rays of the heavenly body observed. This fork is at its other end connected with an axis which is parallel to the axis of the earth, and which is made to rotate with a movement uniform with that of the earth itself.

A graduated circle determines the direction of the axis of the

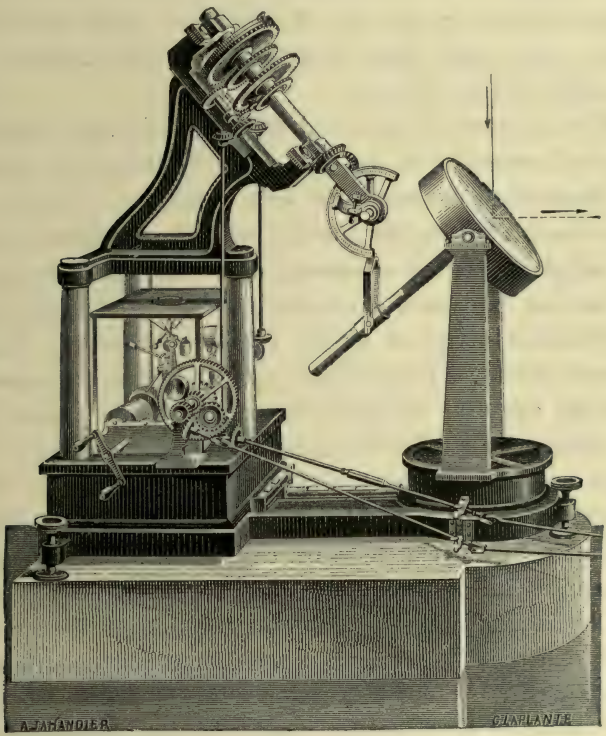


FIG. 153.—The siderostat.

fork, so that the angle which it makes with the axis of the earth varies according to the polar distance of the star. The hour angle of this latter being given the moment when the observer wishes to begin, the instrument is moved in such a manner that the rays of the star lie in the plane which passes through the star and the axis of the telescope, in which they are retained during the time of observation by the clock-

work movement. One of the great difficulties in the manufacture of siderostats is the plane mirror, as its surface must be brought to the greatest possible geometrical perfection. This is the essential difference between a heliostat and a siderostat. In the heliostat, the principle is to obtain a constant direction for the reflected rays ; as it is light which is studied, not the luminous source itself, therefore it matters little if this is represented exactly or not. The siderostat, on the contrary, must give an exact image of the heavenly bodies. This difficult problem of the realization of an optical plane was solved by Léon Foucault by the use of a method which this ingenious physicist, whose early death is greatly deplored, imparted to one of his friends, M. Ad. Martin.

M. Wolf has summed up the advantages of the new instrument as follows—unfortunately, at the time we write, it has not been tested by any observations of sufficiently long standing :—"There is not an observer who has not had to contend with the difficulties presented by the adaptation to an equatorial of a large spectroscope, photographic camera, projection apparatus, or photometric apparatus. All these difficulties disappear by the use of a siderostat. Laboratory instruments, whatever their weight, size, and form, are placed in the focus of the telescope as before the mirror of the camera obscura, and the astronomer studies the light of all the stars under the same conditions as the physicist has studied the light of the sun. By this means experiments, which up to the present time have been almost impracticable, may now be easily made; particularly those which require perfect stolidity of the instrument for measurement, such as the determination of the exact position of the lines of the spectrum, and the displacement of those lines, photometric measurements, &c.

"The mirror of the siderostat, tried with the excellent telescope made by Cauchy, of sixteen centimetres aperture, which belongs to the Paris observatory, with a magnifying power of from 100 to 300 times, does not produce any distortion of the rays proceeding from the star at an angle of more than 45°."

The loss of light occasioned by the reflection is slight. According to Foucault's experiments, it does not exceed in polished silver mirrors $\frac{9}{100}$ of the incident light. Besides, the polish lasts a very long time, and, as the re-silvering is easy, the mirror can be renewed as soon

as the surface changes through any cause.[1] Let us hope that this new instrument, in the hands of skilful observers, will justify the expectations raised by the discoveries and astronomical researches which it renders possible.

[1] The siderostat was made by M. Eichens, under the superintendence of MM. Wolf and A. Martin.

CHAPTER II.

LIGHTHOUSES.

§ I—Marine Signals—The First Catoptric or Reflecting Lighthouses.

LIGHTHOUSES were not unknown to the ancients; for example, the beacon lighted on a high tower in front of the port of Alexandria, and which it appears still existed in the twelfth century. The island on which this tower was built gave its name to the building, which has passed on to all the lights on the coasts for the protection of shipping. Lighthouses were still very few in the middle ages, but increased in numbers in proportion as navigation extended itself, and in the present day, they light up with their various fires, all the coasts frequented by shipping of all nations.

It is only since the last century that people have endeavoured to profit by the laws of the reflection and refraction of light, to increase the power of the lights in lighthouses, and therefore the distance at which they can be seen. In former times they were but simple fires lighted on the top of a tower, and exposed to every change of weather. Gradually, lamps protected by panes of glass were substituted, then came the idea to send the light to a distance, by using reflectors of polished metal. In this way, reflecting or catoptric lighthouses were established. At first they were not a great success; the lamps were defective, and the reflectors being of a spherical form, only received a small fraction of the rays of light, or did not project them in the required direction. "In 1782, this kind of light was established at Cordouan; but, although no fewer than twenty-four lamps, each possessing a reflector, were used, it shed such a feeble

light, that seafarers instantly asked them to return to the primitive method of the middle ages." (*Lighthouses*, by Léon Renard.)

Teulère, an engineer of the last century, substituted mirrors of parabolic form in place of spherical ones. The light from a lamp placed at the focus of the mirror of this kind, is sent out in a cylindrical beam, the intensity of which does not, therefore, diminish with distance. The only lessening of light is produced by the absorption by the atmosphere or fogs. For the ordinary lamps, the same inventor also substituted lamps with the double current of air invented by Argand; later on, Carcel's lamps in which the oil is brought to the burner in a continuous manner by clockwork, again increased the light and steadiness of the burners. Teulère was the first to make his mirrors revolve round a lamp, the burner remaining in the axis of rotation, so that the light was successively projected to every part of the horizon, and then eclipsed. He is also the inventor of the revolving light. A lighthouse of this kind was erected at Dieppe by Borda, in 1784, and another in the tower of Cordouan, six years later, in 1790.

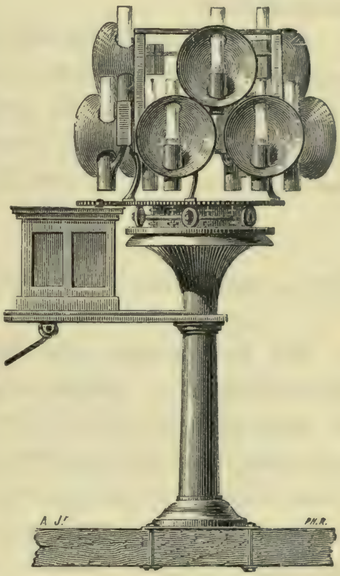


FIG. 154.—Catoptric light.

The catoptric apparatus is generally composed of groups of parabolic mirrors, each having a lamp at its focus. The whole is moved by clockwork. One is represented in Figure 154. It comprises three systems of reflectors, themselves grouped in three, so that a complete rotation gives to each part of the horizon three illuminations and three eclipses. By varying the velocity of the movement, eclipses may be obtained more or less rapidly, and thus the lighthouses established on different parts of the coast, may be distinguished from each other.

The range of the parabolic mirrors is considerable. Experiments due to Biot and Arago prove that a mirror $0^{m}\cdot 81$ aperture gives a

light visible through a glass, at a distance of forty leagues. Nevertheless, the loss of light owing to the reflection or absorption of the rays at the surface of the metal is at least half the incident rays. Moreover, the polished surface of the mirrors is rapidly deteriorated by the action of the saline vapours contained in the air in close proximity to the sea. These inconveniences have caused the catoptric lighthouses to be abandoned, at any rate in first-class lighthouses. In France they are only used for lighting narrow channels, or in addition to a light in a certain direction where the range of the latter is insufficient.

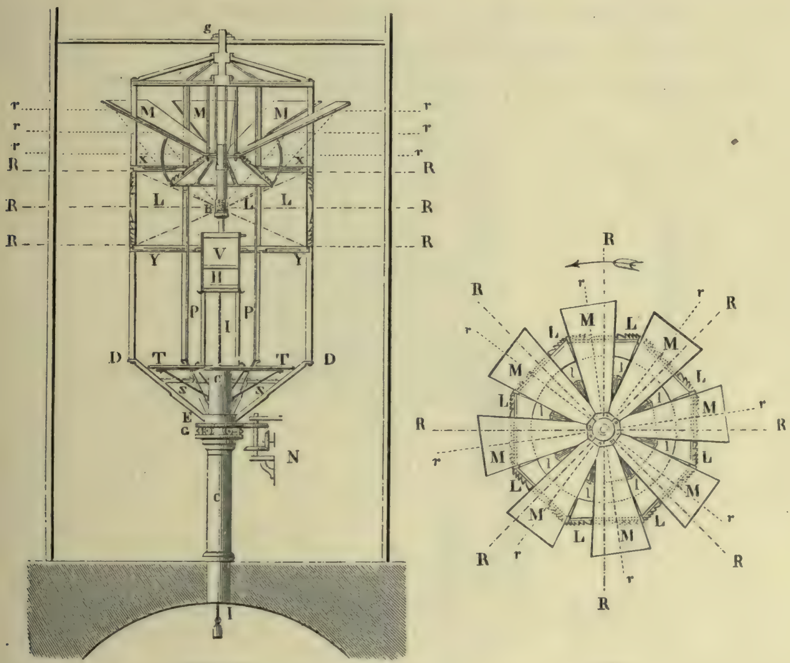
But this abandonment was only possible after the invention of the lenticular apparatus, where refraction is totally or partially substituted for reflection, for the projection of the light; these are called dioptric lighthouses. This invention is due to the illustrious Fresnel, and only dates from the year 1822.

§ II.—Refracting or Dioptric Lighthouses.—Fresnel's Lenses.

We have already seen, in speaking of burning glasses, that Buffon thought of constructing lenses formed of concentric portions of lenses of large aperture, thus lessening the thickness of the glass, and consequently the quantity of the heat-rays absorbed in their passage through the refracting medium. These echelon lenses have, however, not been made on a large scale on account of the difficulties in the melting, cutting and polishing of large masses of glass.

Fresnel who was associated with Arago in the commission nominated in 1819 for the improvement of lighthouses, had the same idea as Buffon, but he greatly improved upon it, and rendered it practicable. In the first place, he made possible and practicable the construction of echelon lenses of large aperture, by forming them of several pieces which can be worked separately, and by subsequently joining all the parts of the lens with a cement of isinglass which causes them to adhere firmly by their edges. In the second place, he profited by this mode of manufacture to improve the form of the refracting surfaces to a degree of which Buffon never dreamt. After saying that if our great naturalist had never made an echelon lens of three feet in diameter it was because the idea never struck him of employing several

pieces, Fresnel adds :—" He had not paid attention moreover apparently to the great advantage presented by the separate working of the surface of each ring which almost entirely corrects spherical aberration, when the rings are sufficiently multiplied, by determining by calculation the centre and radius of curvature of each of the generating arcs. For, after having first conceived the lens determined by a spherical surface, he supposes it to be cut down in echelons, but in such a manner that the new portions of the



Elevation. Plan.

FIG. 155.—Fresnel's first lenticular apparatus: in elevation and plan.

spherical surfaces are concentric with the first, which is not the true way to correct the spherical aberration. Calculation teaches that the generating arcs of the rings not only ought not to have the same centre, but again that these different centres are not situated in the axis of the lens, and that they get more distant from it as the arcs to which they belong are themselves more distant from the centre of the lens; in such a manner that these arcs by revolving round the axis, do not produce portions of concentric spherical surfaces, but to

surfaces called annular by geometers." Fresnel was anticipated however in these improvements by Condorcet[1] in 1788, who not only proposed to build the lens in separate pieces but to vary the curvatures of the different rings in order to correct the spherical aberration. But Condorcet proposed his lens for burning purposes only, while Fresnel was the first who applied the Buffon-Condorcet lens to lighthouse illumination. To utilize in the most complete way possible the rays of light emerging from the lamp placed at the common focus of the set of lenses which compose a dioptric apparatus, Fresnel had the idea of securing the upper rays which would have been lost by trapezoidal lenses arranged all round the lamp with such an inclination that the rays were reflected horizontally in the

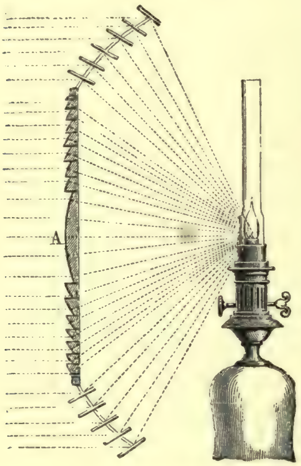


FIG. 156.—Path of rays in Fresnel's catadioptric lighthouse, with lenses and inclined mirrors.

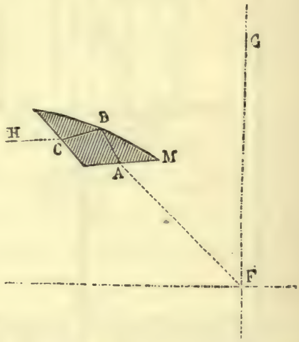


FIG. 157.—Total reflection in the prisms in catadioptric lighthouses.

direction *rr*, by mirrors MM above them. The light R from the vertical lenses was thus greatly added to. Fig. 155 presents the plan and section of a lenticular revolving apparatus such as Fresnel first planned. But Fresnel did not stop with the improvement of the revolving apparatus. His design for fixed lights consisted of a cylindric refracting hoop of glass completely surrounding the lamp, being the solid which is generated by the revolution of a vertical section of his annular lens round a vertical axis. By this instrument the light is parallelized in the vertical plane only, so as to show a fixed light

[1] Histoire de l'Académie Royale des Sciences, Éloge de Buffon, Paris, 1791.

of equal power all round the horizon, while in order to intercept the light above and below the refractor he had a series of zones of silvered mirrors, suitably inclined so as to reflect horizontally; or again by a series of prisms in which the luminous rays undergo total reflection. Figs. 156 and 157 illustrate the path of these rays in each arrangement.

So that reflection and refraction are equally employed in these methods, which for this reason are named catadioptric light-houses.

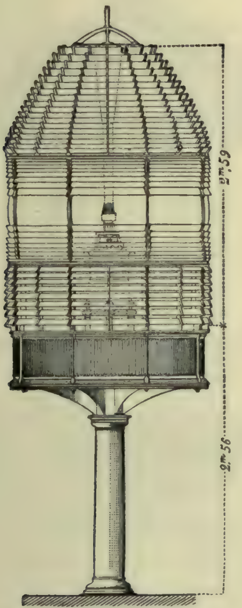


FIG. 158.—Fixed light of the first order and white light.

Fresnel did not stop at these capital modifications; he improved the lamps, and with the assistance of Arago, introduced the system of multiple burners invented by Rumford and successfully combined Carcel's system, giving to the light the greatest possible intensity and regularity, valuable qualities in this kind of application.

A word now on the means used to vary the lights and to afford mariners the advantage of recognizing the coasts wherever they may be.

Light-houses are divided into lights of the first, second, and third order, according to the intensity and the range of their light. In light-houses of the first order the lamps have four concentric wicks, three in those of the second, and two in the third. The brilliancy varies in the ratio of the numbers 4, 2, and 1, and equals twenty, ten, and five Carcel lamps.

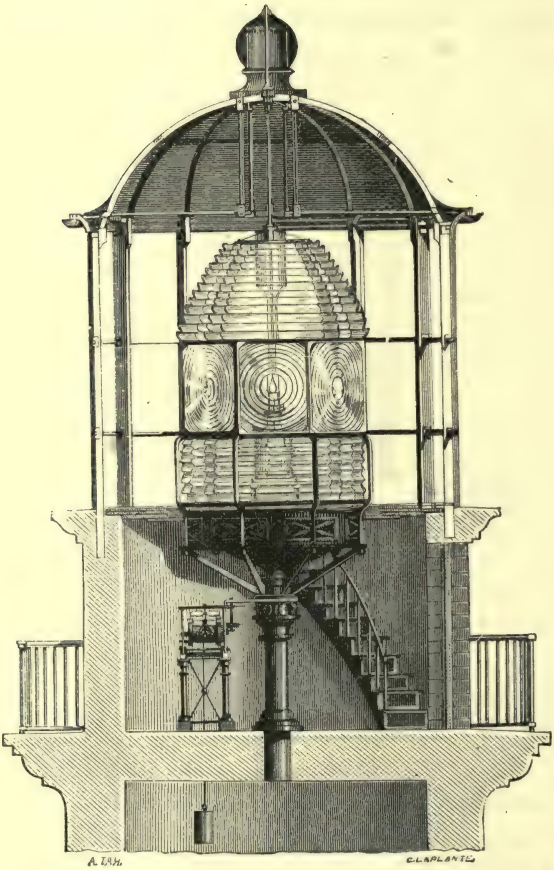


FIG. 159.—Lenticular apparatus and lamp of a first-class revolving light.

So much as to the intensity. Secondly, they vary in their colour. Thirdly, the lights are distinguished by being either fixed or revolving. In the latter a variation is introduced by the length of the intervals which separate the flashes. Thus we have fixed lights produced by a lenticular apparatus of cylindrical form; then

revolving lights, white, red, or green combined diversely with different duration of flash. In the latter the lenticular apparatus is formed by an octagonal drum composed generally of eight simple échelon lenses. The greater or less rapid motion of the system gives place to a

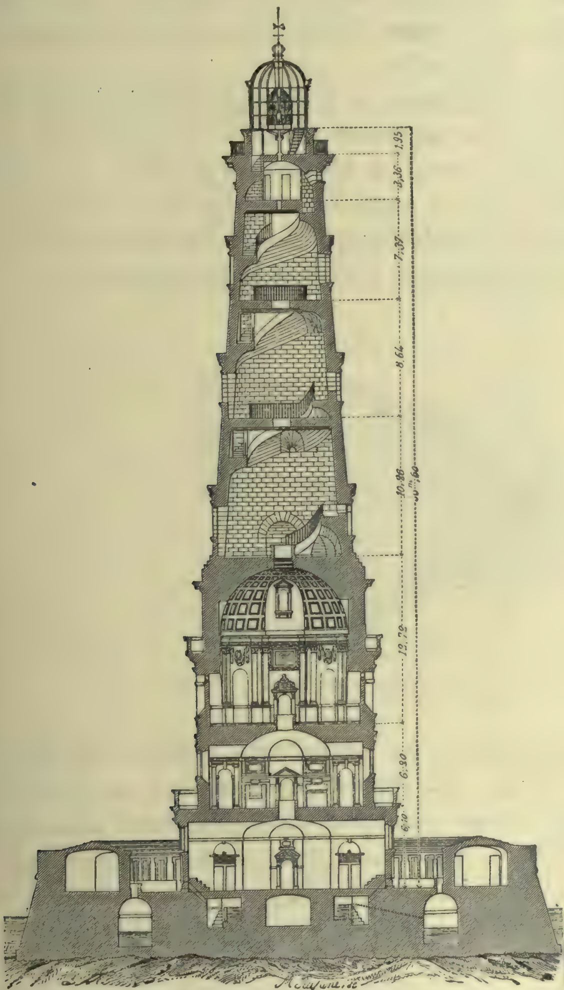


FIG. 160.—Section of the lighthouse at Cordouan.

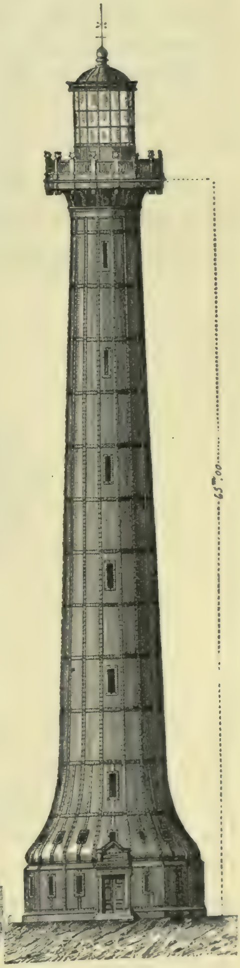


FIG. 161.—The lighthouse at New Caledonia.

succession of appearances—" flashes "—and disappearances of different durations. The colour of the lights is varied by using coloured glasses placed in front of the lenses. Fig. 159 gives an idea how the

machinery is arranged in the lantern which surmounts the tower, and also of the several architectural arrangements of the building itself. The lighthouse at Cordouan has quite a monumental aspect, being entirely constructed of stone. That of New Caledonia, quite recently erected, is on the contrary of sheet-iron and cast-iron. It was made in Paris, then taken to the place of its destination, where it has been for eight years.

In 1849, Mr. Thomas Stevenson, of Edinburgh, suggested what he has termed the holophotal arrangement, which is applicable alike to the catoptric and dioptric systems of lighthouse apparatus. In order to save the light which escapes uselessly past the lips of the parabolic reflector, the following combination shown in Fig. 162 is resorted to: *a* is the paraboloid (in this case truncated at its parameter), L is a

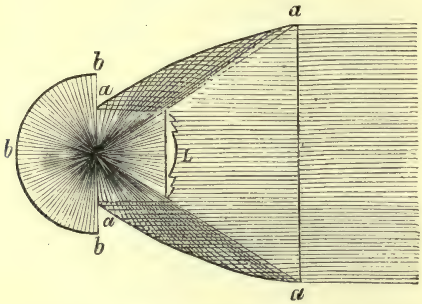


FIG. 162.—Holophotal arrangement.

lens which, at its focal distance for parallel rays, subtends the same angle from the flame as the outer lips of the paraboloid, so that each ray passing outwards is thus intercepted and parallelized either by the lens or the paraboloid. The other half of the rays passing backwards, falls upon the hemispherical mirror *b b* (which takes the place of the apex of the paraboloid) and these rays are reflected back again by its action through the flame so as after again diverging, to be parallelized by the agency of the lens and paraboloid in front. The flame is therefore at once in the centre of the spherical mirror, and in the common focus of the lens and paraboloid.

The above arrangement, though theoretically perfect, is objectionable, on account of the great loss of light which always takes place by absorption wherever metallic reflection is employed. In order to

eliminate metallic reflection from the system, the dioptric-holophote shown in Fig. 163 is employed, in which total reflection takes the place of metallic. L is Fresnel's annular lens, *p p* are totally reflecting prisms, similar in section to those invented by Fresnel for fixed lights, but which are generated by revolution of those sections round a horizontal instead of a vertical axis, and have therefore the property of parallelizing the rays from the flame in every plane, instead of in the vertical plane only, as in Fresnel's fixed lights. These prisms in

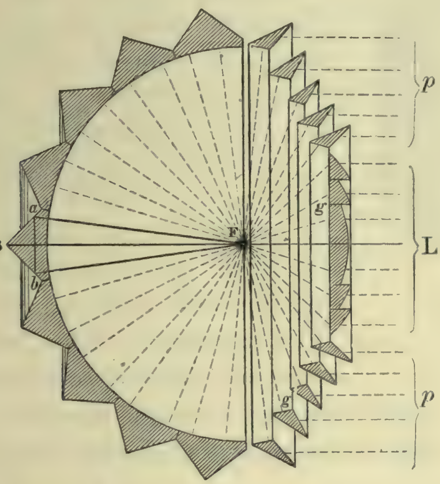


FIG. 163—Dioptric holophote.

FIG. 164.—Section of dioptric spherical prism.

connection with the central lens render parallel one-half of the rays. The rays passing backwards fall upon the prisms of double agency *a b*, and instead of passing through them, as in all other lighthouse prisms, they are after two total reflections sent back through the flame, as shown in Fig. 164, in which the dotted line represents the path of the rays and subjected to the parallelizing agency of the

other optical agents in front. No light therefore reaches the eye of an observer placed behind the apparatus, though between him and the flame the screen is of transparent glass. These prisms of double agency have lately been improved by Mr. J. T. Chance.

In lights of the first order where there is but one great central burner, as in Fresnel's revolving light, Fig. 156, the light passing above the lens instead of being intercepted as in his arrangement by the double agency of inclined lenses and mirrors, is at once parallelized by the single agency of the holophotal prisms as shown in Fig. 165. The application of total reflection to revolving apparatus was first employed at the Horsburgh lighthouse in 1850.

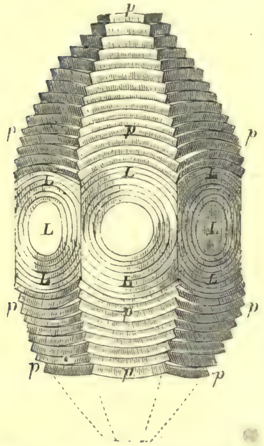


FIG. 165.—Stevenson's revolving light.

In particular cases, depending upon the physical peculiarities of the locality, such as narrow seas and sounds, the whole light must be spread horizontally with strict equality over some one given arc, or in a light of unequal range, where it must be seen at different distances in different azimuths, the light must be allocated to each of such arcs in the compound ratio of the number of degrees and the distance from

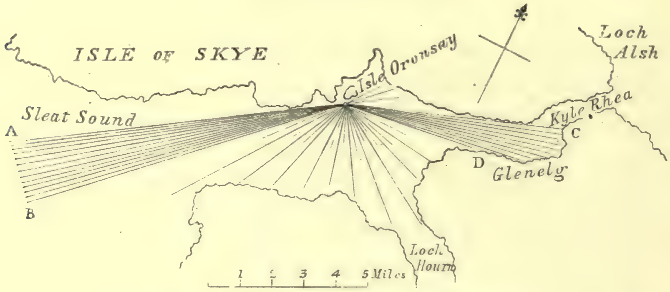


FIG. 166.—Application of azimuthal condensing prisms

which the light requires to be seen. Fig. 166 is a chart showing Isle Oronsay in the Sound of Skye, on the west coast of Scotland, which was one of the three of those azimuthal-condensing lights which were first lighted in 1857. Fig. 167, represents a plan

of this apparatus in which 193° of spare light on the landward side is allocated by the lens B and prisms *a*, and the lens C and prisms *b*, so as to strengthen the light passing down the Sound from the front

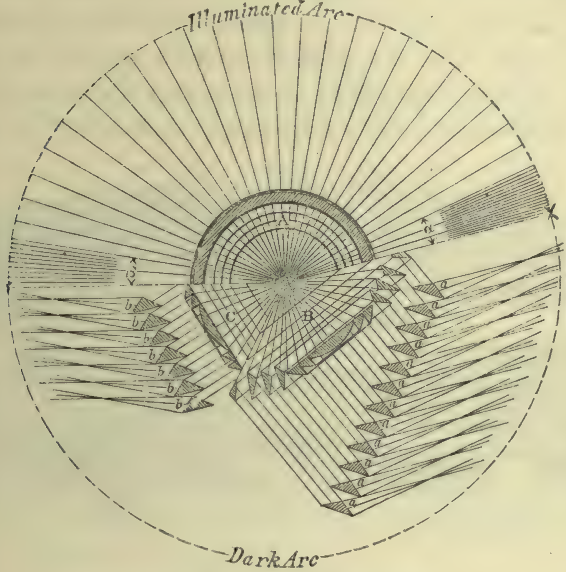


FIG. 167.—Arrangement of the prisms.

apparatus over the arc *α* and up the Sound over the arc *β*. By apparatus of a similar kind the whole light from the flame has been condensed into an arc of 45° at the lights of the Tay, and of 30° at Cape Maria Van Diemen, in New Zealand.

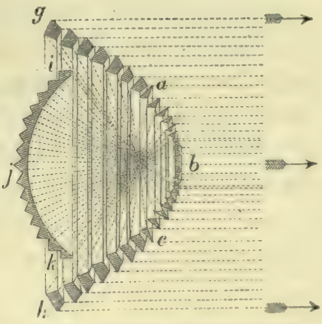


FIG. 168.—Lens at the Lochindall Lighthouse.

Another lighthouse optical agent which was introduced in Scotland in 1869 at Lochindall Lighthouse, is that shown in section in Fig. 168, where it will be noticed that the principle of single-acting prisms has been extended to embrace very large angles behind the flame. These prisms were first proposed by Mr. Stevenson and Mr. A. Brebner, and independently by Professor Swan of St. Andrews.

The only other lighthouse arrangement which it seems necessary

to mention, is that of the apparent light, which was introduced at Stornoway Bay, by Mr. Stevenson in 1852, as shown in Fig. 169, and where, instead of erecting an expensive lighthouse on a sunk rock at sea, a simple perch or beacon was erected, having a lantern on the top containing diverging prisms. A beam of parallel rays thrown from a holophote placed on the shore at the same level as the lantern on the perch, is made after falling on the prisms at the perch to diverge over the required angle of visibility, and in this way the mariner is

FIG. 169.—Apparent light.

led to believe that there is an actual lamp on the beacon, whereas in reality it proceeds from a light on the shore about 650 feet distant.

During the last few years a fresh innovation has been introduced into light-houses. This is the use of the electric light substituted for that of an ordinary lamp, and consequently there is increase of intensity and range. But the dioptric apparatus remaining the same we need not enlarge on this system here as we shall return to it in the book devoted to the applications of electricity.

CHAPTER III.

THE MICROSCOPE.

THE microscope is an instrument intended to aid the sight by more or less magnifying small objects. This is accomplished by so utilizing the principles of optics that the objects are as well seen as if it were possible to observe them very much nearer the eye than at the distance of distinct vision.

There are two kinds of microscopes: the magnifying glass, or simple microscope, and the compound one.

It is very probable, if not absolutely proved, that the ancients understood the magnifying power of glasses of a spherical form. A passage from one of the comedies of Aristophanes proves that the Athenians understood the way to light a fire by using a piece of glass which concentrated the sun's rays. The cylinders and stones, so finely engraved, which are left to us by the Assyrians and Romans, could not have been worked without the assistance of magnifying glasses. Whether these instruments consisted of pieces of glass cut or melted in the form of lenses, or simply hollow glass balls filled with water, is uncertain; but the latter supposition is rendered probable by the following passage from Seneca: "All objects seen through water," he says, "appear larger. Faint and indistinct characters, read through a glass ball filled with water, are larger and clearer to the eye." But if the ancients were aware of the optical power of spheres of water, or glass, or even of glass lenses, it does not seem that they possessed any precise method of using or of making them. They have left no observation in natural history which would confirm the scientific use of the magnifying glass in ancient times.

§ I.—The Magnifying Glass, or Simple Microscope.

A simple convergent, plano- or bi-convex lens, mounted in a form which varies according to its use, is a microscope reduced to the greatest simplicity. This is usually called a magnifying glass or simple microscope.

Fig. 170 represents the path of the luminous rays in the magnifying glass. The object AB is placed at a point nearer the lens than the principal focus. The eye, placed at the converging point F, receives these rays as though they were sent from the points A′B′, that is to say, a direct virtual magnified image of the object.

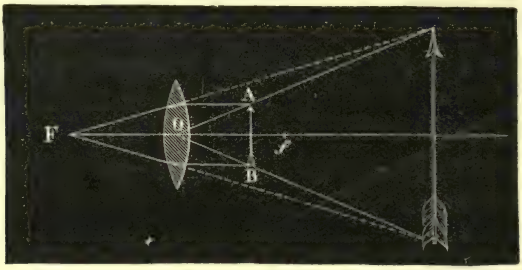


Fig. 170.—Path of the luminous rays in the small microscopes.

In order that this image be sharp, it is necessary that the distance A′F be equal to that of distinct vision, from which it follows that the object must be placed at a fixed point, found by calculation or more easily by actual trial. Very near the principal focus F, and the greater the curvature of the lens, that is, the shorter its focus is, the nearer to this point the object must be. If the object is placed further from the lens, it soon reaches the principal focus f, and the image diminishes in size. If, on the other hand, the object is brought nearer to the magnifying glass, the size of the image increases, but it becomes ill-defined.

Magnifying power of the lens.—In optical instruments the magnifying power in the case of distinct vision is nothing more than the ratio between the apparent diameter of the object, and the apparent diameter of the image. By this is understood the value of the angles

under which the eye sees either one or the other supposed to be placed at the distance of distinct vision.

In the case of the magnifying glass, as the distance from the eye to the lens may be neglected, the magnification is equal to the ratio of the angles A′OB′ and *aOb*, or sensibly to that of the dimensions A′B′, AB, which again is equal to the ratio of the distances OC′ and OC.

The distance OC′ being that of distinct vision, the magnification only depended, as we see, on the distance OC between the object and

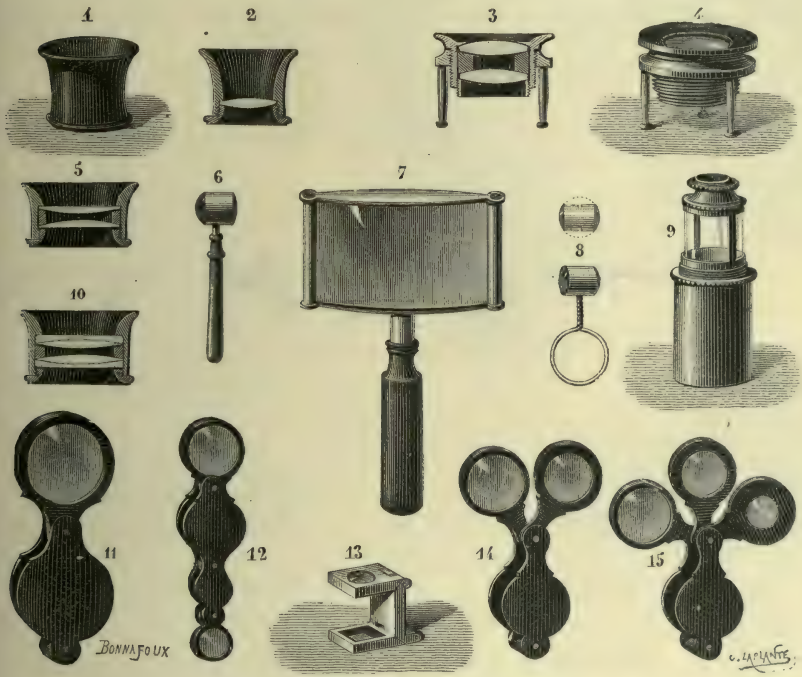


FIG. 171.—Magnifying glasses of different kinds.

1. 2. Watchmaker's and engravers' magnifying glass.—3, 4, 5. Achromatic magnifying glasses.—6. Stanhope lens.—7. Magnifying glass with cylindrical surface.—8. Brewster's (or Coddington's).—9 and 13. Other forms.—11, 12, 14, and 15. Naturalist's pocket magnifying glasses, with one, two, or three lenses of different powers.

the lens, that is from the principal focal distance which differs only slightly from it.

Therefore, the sharper the curves of the magnifying glass, and the longer the distinct vision of the observer, the more considerable will be the magnifying power.

The mounted magnifying glass, shown in section and perspective

in Fig. 171, 1, 2, is that most used by watchmakers and engravers. It is held in the hand or even by the eye, where the observer retains it by an effort of the muscles of the eyebrows and the cheek; in this way the hands remain free; but it is best to adapt it to a support or upright stand (Figs. 172 and 173).

The magnifying power of these lenses rarely exceeds five times; they possess, moreover, a serious defect: that is, the spherical aberration is very great. The proof of this is easy. If you look at an object of a certain size with one of these lenses, it will be seen that the image is only sharp in the centre: at the edge it is deformed and

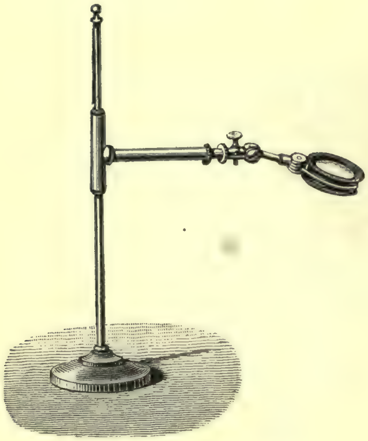


FIG. 172.—Support for lens.

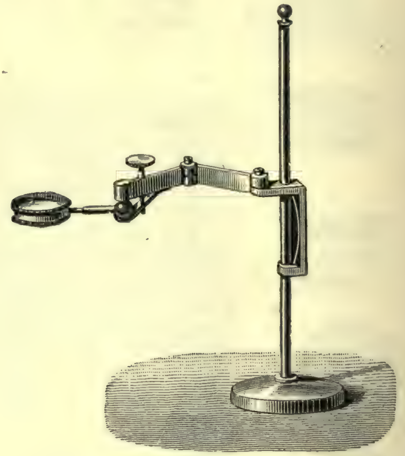
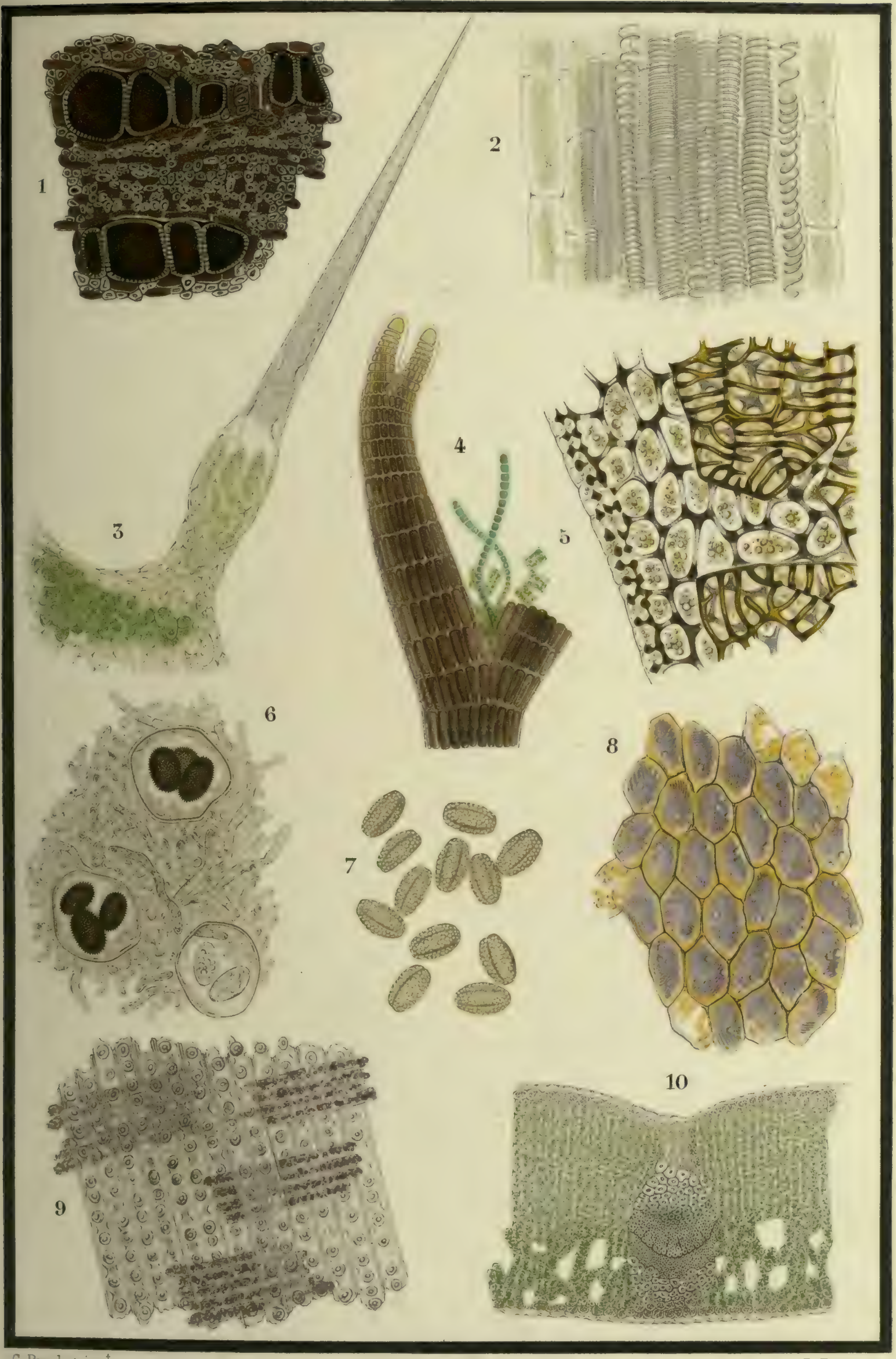


FIG. 173.—Another kind of stand.

ill-defined. Moreover, it is coloured, which shows another defect—that simple lenses lack achromatism. But they have an advantage which partly compensates for these inconveniences: that of a large field; the great focal distance leaves space for the movement of the hands and the objects below the lens, and work may be carried on without inconvenience.

Spherical aberration is diminished by applying a diaphragm or opaque annular plate to the edges of the lens; this stops the rays from this part of the lens, but the field is thereby diminished.

The magnifying glasses represented at Fig. 171, 11, 12, 14, and 15, are used by naturalists. The same mounting encloses two or three



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THE MICROSCOPE

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different magnifying glasses; these instruments are then called double and triple lenses.

To destroy spherical aberration and achromatism at the same time the magnifying glass must be built either of two plano-convex lenses, their convexities facing each other, or of two perfectly achromatic lenses, each formed of two glasses properly chosen, the curves being so calculated as to entirely destroy the spherical aberration.

Wollaston's periscopic magnifying glass and Brewster's or Coddington's lens are on the same principle, that is, the diaphragm is placed in the interior; the glass is a cylindrical sector cut out of a sphere. The middle of the cylinder is grooved, so as to form a diaphragm; a magnifying power of 30 times may be obtained with this lens.

The Stanhope lens is also formed of a glass cylinder, but the curvature of the two surfaces is not the same. By placing small transparent objects which are to be examined, such as pollen grains, the scales of butterflies' wings, etc., on the flat surface, and by turning the lens up to the light, bright images are obtained, sometimes magnified 40 times.

§ II.—The Simple Microscope—Wollaston's Doublet.

The simple microscope (invented by Cuff, and called also Raspail's microscope) is a magnifying glass mounted on a brass stand furnished with a stage, on which the object to be examined is placed. Below the stage a plane, or concave mirror, is arranged to throw the light on the object to be examined. By a rack and pinion motion, either the magnifying glass or the stage can be raised or lowered in order to bring the object to a focus—that is to say, to place it in the most favourable position for the production of a clear image, a position which varies with individuals and the magnifying powers made use of. The stage is constructed with an opening, which allows the light sent by the mirror to pass, and the object is placed on a glass plate above the opening.

Fig. 174 represents a more complicated simple microscope. There are two magnifying glasses, which may be inclined, so that all sides of the object may be examined.

Instead of a single lens, such a microscope is often fitted with a magnifying glass formed of two lenses, separated by a diaphragm, in order to destroy the spherical aberration and to secure achromatism.

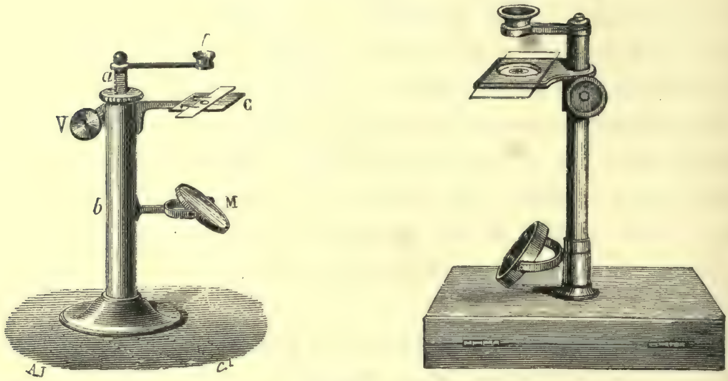


FIG. 174.—Simple microscopes.

Such a combination is Wollaston's doublet. Fig. 175 represents a doublet with improvements by Ch. Chevalier.

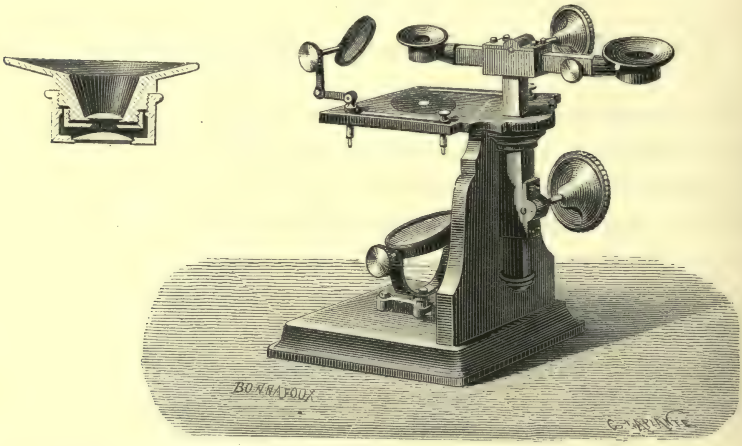


FIG. 175.—Simple microscope with doublet.—Wollaston's doublet, improved by Chevalier.

The compound microscope fulfils this object: it possesses magnifying glasses with convex lenses of different powers and fields, which may be used at pleasure.

The ordinary lens and the simple microscope have done great service to the sciences. The latter is especially used for the preparation and dissection of objects principally in vegetable anatomy, for histologists prefer the compound microscope for the dissection of animal tissues. In this case the magnifying power rarely exceeds 60 times, because, with more powerful magnifications, the focus of the lens is so short that there is no room for manipulation. For simple observations doublets may be used, which magnify 500 times; but, in this instance, the focus of the magnifying-glass is not the half of a millimètre from the object.

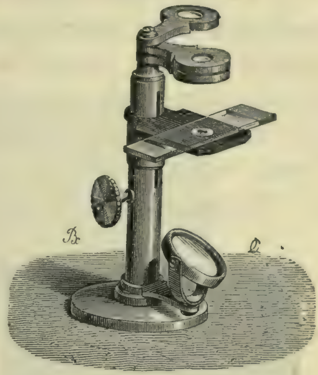


FIG. 176.—Compound microscope.

§ III.—THE COMPOUND MICROSCOPE.

In the compound microscope there are two systems of lenses; the one called the eye-piece, because it is placed nearest to the eye; the other, the object-glass, because it is turned towards the object which is to be magnified. In the most simple and rudimentary instruments the object-glass is a bi-convex lens, which furnishes an already magnified but reversed image of the object. It is this image which is examined by the eye-piece, which therefore acts as a magnifying-glass; with this exception, that the magnifying-glass magnifies the image and no longer the object.

Fig. 177 shows the path of the luminous rays in such a compound microscope. O′ is the eye-piece, and O the object-glass, in front of which is seen the little object *ba*. The object-glass produces an enlarged image at the focus of the eye-piece. This image, which in turn serves as an object to the eye-piece, is reversed, and, as the eye-piece only magnifies it without correcting it, the eye sees the object reversed, as if it were at AB—that is, at the distance of distinct vision.

Such is the optical apparatus of the compound microscope, reduced to the most simple statement, for the sake of making the

general construction easily understood. For high magnifying powers such an instrument would be altogether worthless for want of good definition. It is possible, on this system, as in the case of the simple lens, to partially correct the errors either of the object-glass or of the eye-piece with regard to spherical and chromatic aberration, but far more complex arrangements are necessary to obtain first-rate results with high powers.

The first fault is corrected by limiting the extent of the real image by means of a diaphragm placed at the focus of the eye-piece—that is, at *ab*. But as this also limits the field of the microscope, an eye-piece of large diameter is used, having in consequence a more extended field. To the same end an eye-piece is used with a system of two plano-convex lenses, one called the field lens and the other the eye lens, the convexity of which is away from the eye. This is Campani's eye-piece, Fig. 178, in which the chromatic aberration is somewhat diminished. SI is a luminous ray proceeding from the object; on being refracted, it is divided into coloured rays, the red following the direction IR, and the violet IV, so that the eye would see the edge of the object coloured if the second eye-piece did not make the coloured more parallel at B′, where the eye is placed to make the observations.

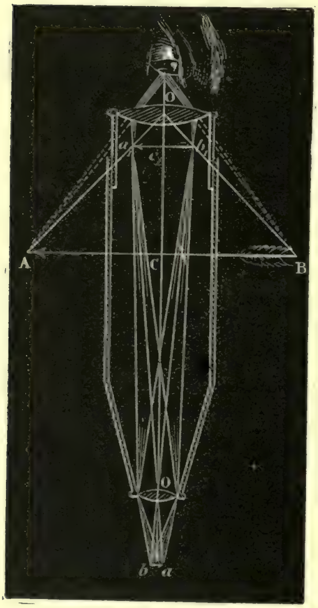


FIG. 177.—Path of the luminous rays in the compound microscope.

Achromatism is also obtained by making the object-glass of two lenses, one of flint and the other of crown glass, the latter bi-convex, and the former divergent (Fig. 179), the curves being so regulated that the greater dispersive power of the flint glass to a great extent counteracts the less dispersive power of the crown glass, but only partially counteracts the magnifying power.

The best modern object-glasses are, however, far more complex. Until quite recently they were constructed of three sets of lenses, each an approximately achromatic combination of a plano-concave of

flint and a double-convex crown glass; but with the very highest powers various combinations of lenses of those two kinds of glass are now used, some to magnify and others to correct the errors, that,

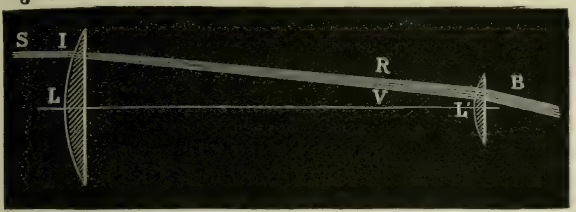


FIG. 178.—Campani's achromatic eye-piece.

after passing through the compound eye-piece, the image may be approximately free from chromatic and spherical aberration. The accuracy of workmanship necessary to accomplish this is so great, that satisfactory results can only be obtained by repeated trials, and by what may often be called accidental good fortune.

The magnifying power given by the compound microscope is a combination of the magnifying power of the object-glass multiplied by that of the eye-piece. Let us suppose the real image furnished by the first system magnified twenty times; if the eye-piece magnified it again five times, it is evident that the total magnification will be 100 times.

In this it must be well understood that we refer only to linear dimensions or to diameters. Superficial magnification is evidently equal to the square of this. Thus if your object has been magnified 50, 100, or 500 diameters, the surface of the object has been magnified 2500, 10,000, 250,000 times, but no practical microscopist thinks of expressing his results in any other terms than linear magnifying power.

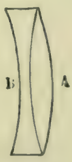


FIG. 179.

According to M. Arthur Chevallier, compound microscopes are now constructed with optical systems, divided into nine series according to the magnitude, from number 1, which gives a power from 25 to 50 diameters, to number 9, which magnifies from 600 to 1,300 times. With this last magnification, the surfaces are multiplied by the enormous number, 1,690,000. It is, therefore, possible to examine portions of matter of the size of the thousandth part of a millimétre. But it must not be forgotten that the art of using a microscope

is only acquired after long practice, and very much depends on using suitable illumination. The eye must be educated to use the highest powers; and students who wish to possess the skill of their masters will do well to begin their observations by the gradual use of low powers. We will also remark that, as the

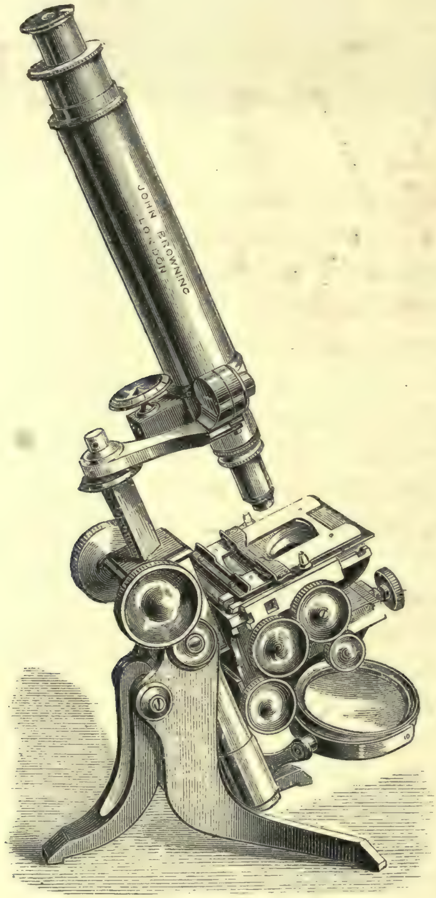
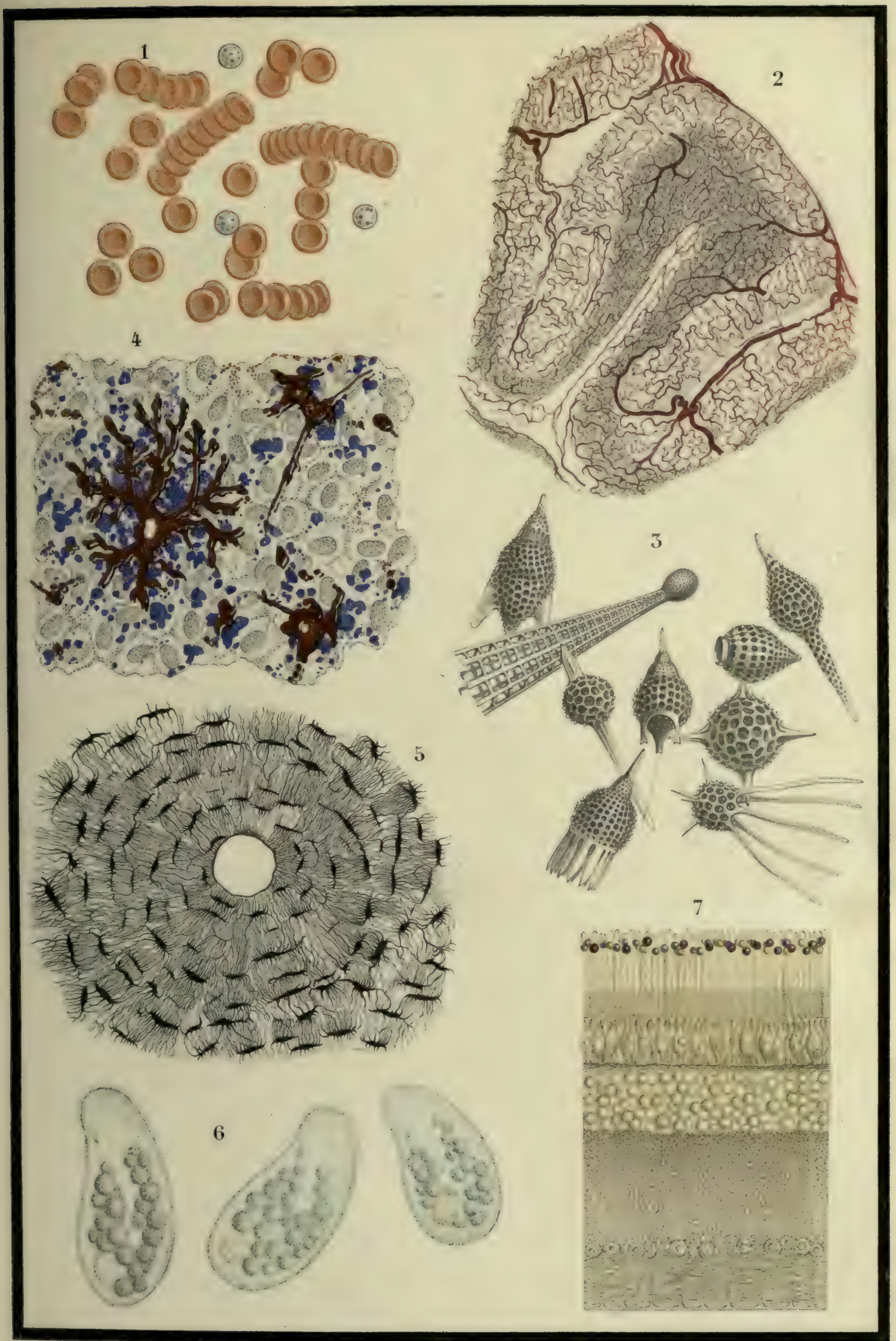


FIG. 180.—English form of inclined microscope.

greater the magnifying power, the more the light which illuminates the object and renders it visible is divided and diffused, the more necessary it is to have a brilliant light. As a rule no higher power should be used than is necessary to see any particular



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structure under examination; for, not only is the field of view

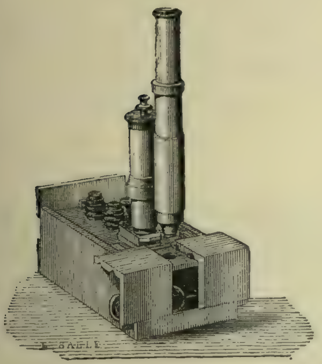

FIG. 181.—Compound microscope mounted on stand.

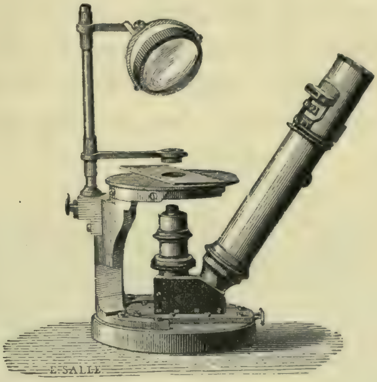

FIG. 182.—Microscope used by chemists.

diminished, but, unless the lenses be of the very best construction,

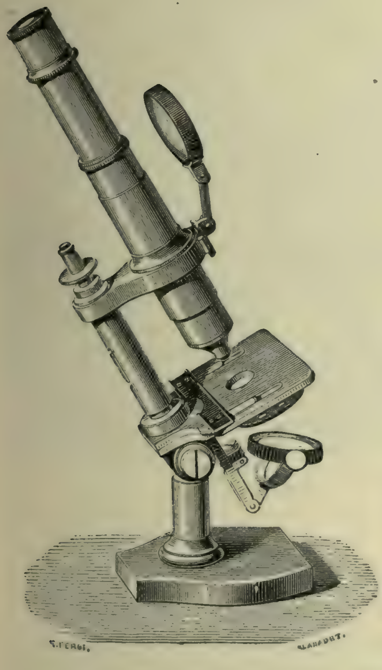

FIG. 183.—Nachet's inclined microscope.

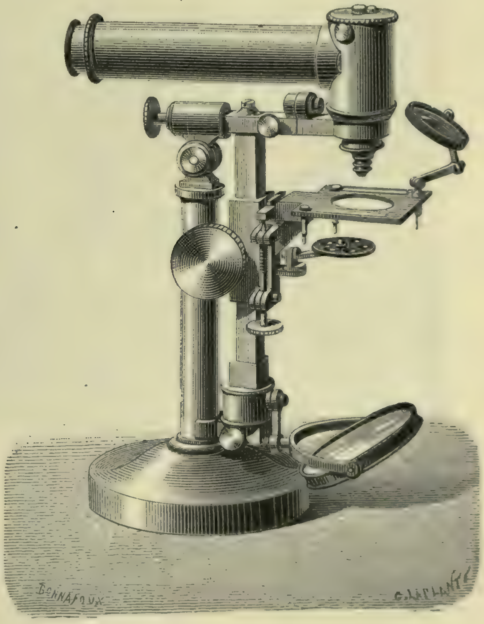

FIG. 184.—Amici's horizontal microscope.

though the object may look larger, no more detail will be seen.

R 2

We will now examine some of the arrangements adopted by makers of compound microscopes.

As in the simple microscope, we have to deal with it as three principal parts: the optical apparatus, which contains the eye-piece and object-glass, inclosed in a tube; the stage, which is of various forms, but generally made of a plate pierced with one

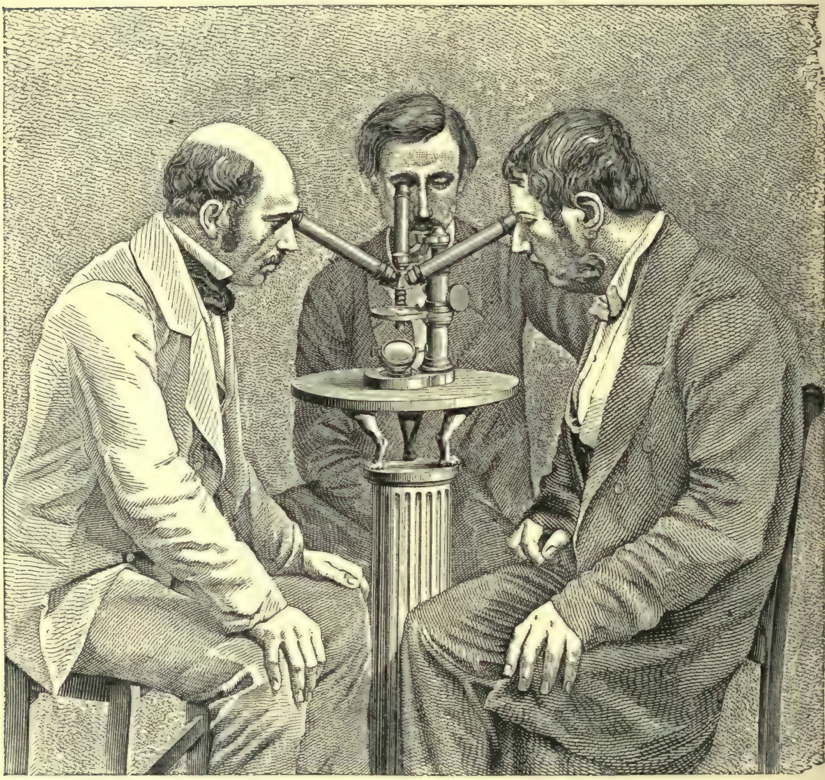

FIG. 185.—Microscope with three tubes for simultaneous observers.

or more circular openings, on which the glass which carries the object is placed; lastly, the mirror, which reflects the light on the object. If the object is not transparent, it is lighted from above by means of a lens arranged laterally, and moving in different directions.

Sometimes the optical tube is vertical (Fig. 181), which of course

has the merit of simplicity, but this is the very worst position for the optical performance of the human eye. Sometimes it is capable of being inclined obliquely at various angles (Figs. 180 and 183); which is by far the best plan if the workmanship be good; sometimes, indeed, as in Amici's microscope (Fig. 184), it is bent at

FIG. 186.—Arrangement of tubes in Wenham's binocular microscope.

right-angles; the horizontal part incloses the eye-pieces, and the vertical part the object-glass; at the bend a mirror, inclined at 45°, or a prism, reflects the luminous rays coming from the object-glass, and sends them horizontally into the eye-piece.

Microscopes are also constructed with three bodies, which enables simultaneous observations to be made by three different persons. These instruments are valuable in the study of micrography.

To obtain images in relief, which cannot take place when observed with one eye only, binocular microscopes are now constructed. In Nachet's arrangement (Fig. 187), the image formed by the object-glass is divided into two portions, which are reflected to opposite sides, and again reflected up two parallel tubes, placed at the width of the eyes, each having an eye-piece. In the form introduced by Mr. Wenham (Fig. 186) the image is divided into two parts by a prism, which by a double reflection bends one at an angle and throws it up one tube whilst the other part passes direct up the other tube. Another system, introduced by Mr. Stephenson, has the advantage of giving far better results with high magnifying powers. The necessity of this arrangement will be understood when we study stereoscopic vision.

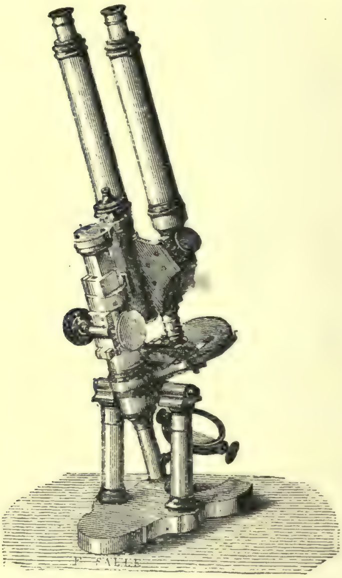

FIG. 187 —Nachet's binocular microscope.

Lastly, special microscopes are made (Fig. 182) in which the eye-piece tube is inclined, and terminates *under* the stage. A prism sends the luminous rays in the direction of the eye by total reflection. These instruments are made for chemists to examine objects through the glass bottom of a small vessel containing a liquid.

Within the last dozen years spectrum analysis has been applied to microscopical research by Mr. Sorby, to study accurately the exact nature of the light transmitted by, or reflected from, minute coloured objects. This is usually accomplished by means of a special eye-piece, containing a slit and compound direct-vision prisms, and an arrangement so that the spectrum of another object on a side stage may be compared with that of a smaller object magnified by the object-glass. By another plan the spectrum apparatus is placed under a special object-glass of long focus, so that it can be used with a binocular microscope and the spectrum seen with both eyes.

We shall terminate this description of microscopes by mentioning

an instrument employed to throw magnified images on a screen at a distance, in order to render them visible to a large number of spectators at the same time. This is the solar microscope, described in the *Forces of Nature,* and which is thus called because the light with which the object is illuminated is the light from the sun's rays. When the sun does not shine it would be necessary to relinquish this powerful means of demonstration in laboratories

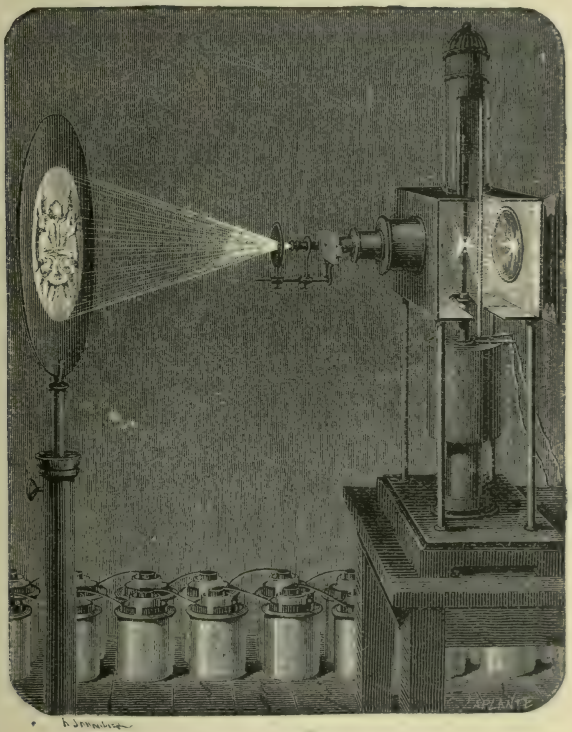

FIG. 188.—Photo-electric microscope.

if we did not possess a source of nearly as bright a light as the sun. We refer to the electric light. Therefore, we have the photo-electric microscope, represented in Fig. 188.

There is an important application in microscopy, which must not be passed over in silence. This is the photography of the objects thus observed in all their exact and curious details, by which means permanent and exact records may be secured.

To give an idea of the immense services rendered to science by the microscope, to initiate the reader, who has not this valuable instrument at his disposal, into the wonders of the world of the infinitely small, we reproduce in coloured Plates some specimens of objects seen with the microscope, taken from the three great branches of natural bodies—animal, vegetable, or mineral. We are indebted for these beautiful plates to the kindness of M. Georges Pouchet, sub-director of the Histological Laboratory, directed by M. Robin, and to the skill of an able draughtsman, M. Deyrolle.

CHAPTER IV.

THE TELESCOPE.

THE microscope enables us to penetrate into the mysteries of the infinitely small; it places the most minute objects within range of human sight, and exhibits in a distinct manner the thousand details with which the unaided eye is powerless to deal.

That which the microscope does for objects within our reach, but too small to be visible, the telescope realises with a similar power for objects which are rendered indistinct by distance, whatever their real dimensions may be. It fathoms the depths of space, and presents to the view, stars, the existence of which, without its help, would scarcely ever have been guessed; while with regard to those which can be seen with the naked eye, it reveals to science the details of their structure, and thus multiplies for our curiosity the objects which nature offers to observation, and by the aid of which human intelligence interprets her laws.

The word telescope is taken from the Greek, as in the case of the microscope; both have a common root, σκοπέω (*scopeô*), I look, μικρὸς (*micros*), small, and τῆλε (*têle*), afar. Etymology therefore applies the word telescope to all instruments which magnify objects and bring them nearer to the eye. Thus we have refracting telescopes, that is, instruments formed of certain combinations of glasses or lenses; and reflecting telescopes, that is, instruments with a mirror or reflector.

§ I.—REFRACTING TELESCOPES.

With regard to the date at which telescopes were invented, and the name of the inventor of this wonderful instrument for celestial and terrestrial investigation, there is some uncertainty, as in the case

of many other scientific discoveries; only, in this case, we may be certain that the idea of combining lenses to form a telescope does not belong to ancient times, or even to the middle ages. The first mention of it is towards the end of the sixteenth century, when Porta found that by combining two lenses, the one concave and the other convex, "near, as well as distant objects could be magnified and rendered distinct." But it was a Middelburg optician, Jean Lippershey, who was the first to realise this combination, and constructed the first telescopic lens (1606). Jacques-Adrien Metius in 1608 and Galileo in 1609 appear to have solved independently Porta's optical problem; but it must be said that the great physicist and astronomer of Florence had heard of Lippershey's discovery without having had any exact account of the instrument itself.

Now, how did the Dutch optician discover this? On this point nothing is positively known, as is proved by the fact that there are two versions—two different legends on the subject. According to Arago these are as follows:—

Hieronymus Sirturus relates that a stranger, either man or demon, presented himself at Lippershey's and ordered several convex and concave lenses. On the day agreed upon he called to fetch them, and chose two, one concave and the other convex. After having looked through them and by degrees separated one from the other without saying whether he did this in order to test the work of the artist or for any other reason, he settled his account, and disappeared. Lippershey forthwith set about imitating what he had seen, noticed the magnification induced by the combination of the two lenses, fixed the two glasses at the extremities of a tube, and hastened to offer the new instrument to Prince Moritz of Nassau.

According to the other version, Lippershey's children playing in their father's shop, bethought themselves to look through two lenses, one convex, the other concave; these two glasses being placed at a proper distance, showed the weather-cock on the Middelburg steeple magnified and brought nearer. The surprise of the children having awakened Lippershey's attention, he, to make the experiment more conveniently, at first attached the glasses to a plank; afterwards he fixed them to the extremities of two tubes which slid one into the other. From this moment the refracting telescope was discovered.[1]

[1] Arago, *Astronomie Populaire.*

A refracting telescope, or, as it is termed shortly, a refractor, like a compound microscope, is composed of two essential parts—two systems of lenses. The one nearer the object is called for this reason the objective or object-glass : this is generally a biconvex lens with a long focus, which produces a real and inverted image of the object. The eye is applied to the other system of lenses called the eye-piece : this is a simple or compound magnifying-glass, by which the image, which is in a certain measure magnified, is examined.

In the first telescopes the eye-piece was a biconcave lens, as we have already seen ; the inverted image formed by the object-glass is corrected in this system, as will be seen by the path of the luminous rays represented in Fig. 189. The object-glass O gives at its focus, which for very distant objects is the principal focus of the lens, a

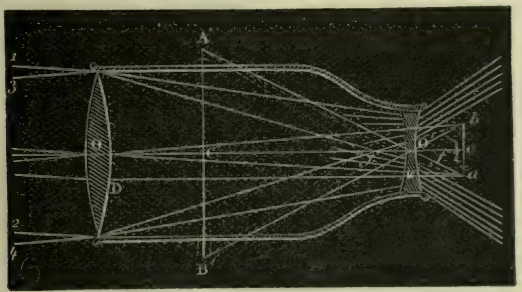

FIG. 189.—Path of luminous rays in Galileo's telescope.

real image *ba* of the object observed. This image is inverted, which may be proved by letting it fall on a screen. The bi-concave O′ being placed between the image and the object-glass causes the luminous rays to diverge and thus prevents the formation of the real image. To the eye, into which these rays penetrate after leaving the eye-piece, they appear to come from the points A′ and B′ situated on their optic axes at their points of convergence. This gives a virtual erect image A′B′, which is well defined if the lenses are arranged so that this image is formed at the distance of distinct vision. There is an essential difference between the magnifying power of refracting or dioptric telescopes and that of microscopes. In these latter instruments the magnified image is larger than the object itself, that is to say, the angle subtended by the image is greater than the angle

subtended by the object, the image and the object both being at the same distance from the eye. In refractors, on the contrary, and this applies to all kinds of telescopes, the image is always of smaller dimensions than the object itself; but it is larger than the image furnished by the naked eye, and this constitutes the magnifying power of refractors.

The eye-piece is movable in the tube which holds the object-glass; a milled head, which works with rack and pinion, enables the distances between the glasses to be adjusted. In this way an image of perfect sharpness is obtained. This is called focussing. Short-sighted people shorten the tube and long-sighted lengthen it in order to see distinctly.

The magnifying power in all telescopes depends upon the ratio of the focal length of the object-glass to that of the eye-piece.

The telescope we have just described, with two lenses, has received the name of Galileo's telescope, it shows objects erect at the same time that it brings them nearer and magnifies them.

Galileo's first telescope only magnified from four to seven times in diameter; the most powerful that was made and used by the illustrious astronomer magnified thirty-two times. That enabled him to make a number of discoveries which then were justly considered wonderful; the mountains in the Moon, the spots and rotation of the Sun, Jupiter's satellites and the phases of Venus, the breaking up of the great nebulosity called the Milky Way into stars, &c. His *Nuntius Sidereus,* which he published to inform the scientific world of his results and researches, scarcely sufficed to record these discoveries, which soon formed a branch of astronomical study unknown to the ancients.

In the present day, Galileo's arrangement is no longer used for astronomical instruments, its magnifying power is too feeble; but it is employed as a terrestrial glass, and especially for the examination of near objects; it is nothing more than the Opera-Glass, a very convenient instrument, because, with equal magnifying power, it is of much shorter length than refractors with converging eye-pieces. The field is small, and as the rays diverge on leaving the eye-piece, it is necessary to place the eye very near the latter so as not to lessen the field still more.

It is now time to say a word on the improvement made in the

construction of optical instruments by an English optician, of French origin, named Dollond.[1] We refer to the achromatism of the lenses, of which we have spoken when describing the microscope.

When a ray of white light is refracted by a lens, the coloured rays of which it is composed not having the same degree of refrangibility are dispersed, and give to the images formed fringes of prismatic colours, which constitute a serious defect in the production of sharp and true definition. This dispersion is caused because each of the coloured rays has a distinct focus at a different distance from the lens. This defect is called chromatic aberration, and Dollond

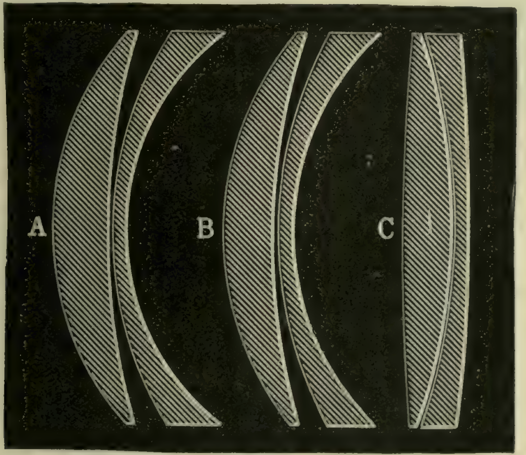

FIG 190.—Achromatic lenses: A, Gauss' object glass; B, C, Herschel's object glass.

discovered a method of counteracting this by making the object-glasses and eye-pieces of two or more different lenses, either convergent or divergent, and varying the nature of the glass of which these lenses are formed.

By forming the converging lens of ordinary crown-glass and the diverging lens (bi-concave or plano-concave) of flint-glass; and by giving certain curves to each surface of the combination furnished by calculation or experiment, Dollond made systems of achromatic lenses, so that the rays of white light, on being refracted in the desired direction, retained their parallelism on leaving the lens,

[1] Dollond was descended from a French Protestant family, which the Revocation of the Edict of Nantes obliged to take refuge in England.

in a word, they were not dispersed. Since that time the combinations necessary to give achromatic systems have been very varied.

In every carefully-constructed instrument this defect of chromatic aberration is suppressed or at least considerably lessened.

FIG. 191.—Opera glass with achromatic object-glass and eye-piece.

In Galileo's telescope achromatism results partly from the circumstance that the eye-piece is a divergent whilst the object-glass is a convergent lens. By taking care to make the eye-piece of flint glass and the object-glass of crown, the system will be achromatic; but in this case the curves of the lenses would only give a very slight magnification, insufficient for general use. Lenses are therefore preferred in which achromatism is obtained separately.

Fig 191 represents an opera-glass, in which the combinations adopted for the eye-piece and object-glass may be seen. The latter is formed of a bi-concave flint glass lens inclosed between two convex lenses of crown glass, whilst the eye-piece is a convex lens of flint glass placed between two concave lenses of crown. Sometimes the object glass alone is achromatic and the

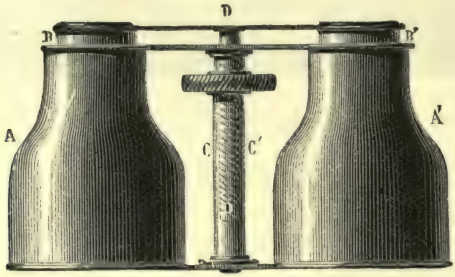

FIG. 192.—Double or binocular opera-glass.

curve of the eye-piece is calculated in order to increase the magnifying power.

§ II. The Inverting Telescope.

We now come to an instrument of slightly different construction, the refracting telescope, generally used in the present day for surveying and astronomical observations. This instrument consists essentially in a system of two converging lenses: the object-glass, giving a real and reversed image of the object; the other, the eye-piece, magnifying the first, but preserving its inverted position. As a matter of course the two lenses are both compound so as to produce achromatic images. By the help of Fig. 193, the path of the luminous rays in this instrument may be traced, and we shall easily see how it differs from Galileo's telescope.

The rays starting from the upper extremity of the object, supposed to be situated at an infinite distance, form a parallel beam 1, 2, until

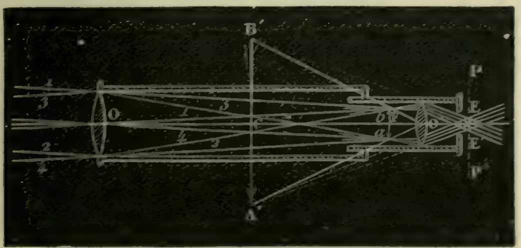

Fig. 193.—Path of the luminous rays in the inverting telescope.

they reach the object-glass O. On passing through this latter, where they are refracted, they form, by their convergence at a, an image of this extremity. In the same way the beam 3, 4, coming from the lower part produces a real image b. Thus we have a reversed image of the object at the principal focal distance of the object-glass, at ab. This image the magnifying glass or eye-piece O′, magnifies, at A′B′, that is, at a distance from the eye equal to the distance of distinct vision.

As in Galileo's telescope, the magnification depends upon the ratio between the focal distances of the object-glass and of the eye-piece. Therefore, the longer the focus of the object-glass, and the shorter the focus of the eye-piece, the greater becomes the linear magnification.

The value of the magnification is expressed in another way when the eye-piece is composed of a system of lenses.

Fig. 194 shows the inner arrangement of the inverting telescope.

The eye-piece is generally formed of two plano-convex lenses separated by a diaphragm and adapted by a sliding tube inside the larger tube which holds the object-glass.

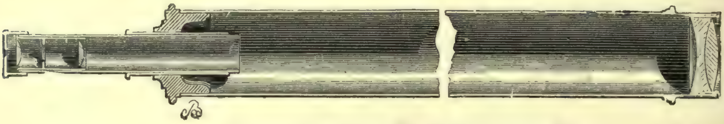

FIG. 194.—Inverting telescope ; section or inner view.

By an external milled head V, the tube of the eye-piece is drawn in or out, in order to focus it, that is to say, to bring it into the position where the image is formed perfectly distinctly. This depends both on the magnifying power used and on the observer's eye, and for objects comparatively near, on the distance of these objects themselves. For celestial objects, as their distance may be regarded as infinite, the

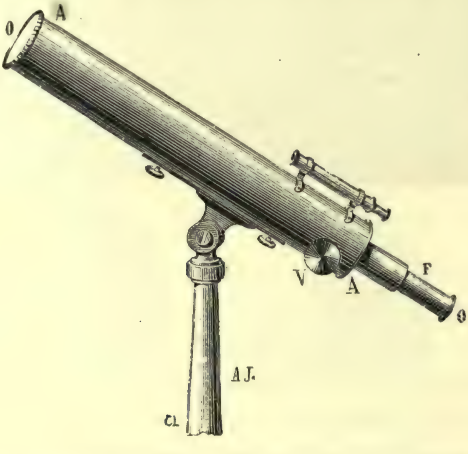

FIG. 195.—Astronomical refractor with finder mounted on ordinary stand.

change of focus is only required by change of magnifying power, and the observer's eye which may be normal, near, or far-sighted.

The applications of this kind of telescope are very various, as by its construction it is possible to insert in the eye-piece cross wires, by which it can be very accurately directed to distant objects. Hence,

in all levelling operations such a telescope is employed with a system of levels and sometimes a horizontal circle. For surveying, a finely divided vertical as well as a horizontal circle is attached, and we have the *Theodolite*, Figs. 196 and 197, by which from any spot one can determine the horizontal and vertical angles of distant points, and so map a country.

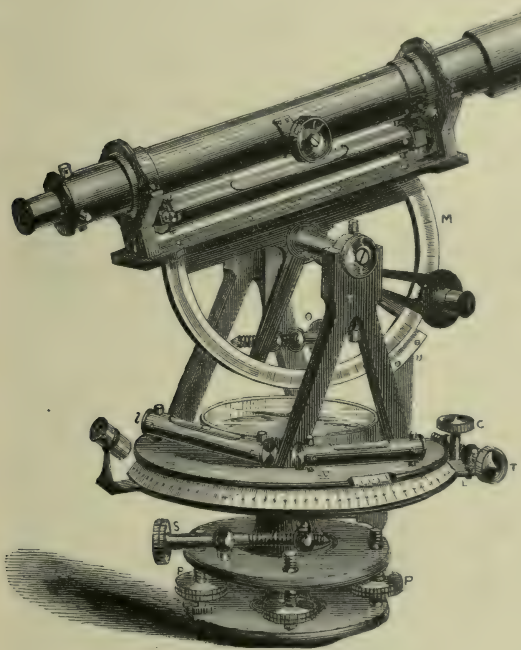

FIG. 196.—Theodolite level.

As the inversion of astronomical objects presents no disadvantage, such an instrument is almost invariably used for all astronomical purposes which do not require the maximum of light; for these reflectors are brought into play, as we shall see further on.

Fig. 195 shows a telescope mounted on a stand for ordinary astronomical observations. When it is required accurately to determine the position of stars, the telescope is mounted so that it may command either all the heavens, in which case we have the astronomical equivalent of a theodolite called an *alt-azimuth instrument;* or so that its observations are confined to the plane of the meridian, in which case we have the transit circle, Fig. 198.

When the largest telescopes are used other arrangements are adopted.

To the telescope another small telescope, called a finder, is fixed parallel to the principal one, and its field of view is furnished with two threads or spider lines crossed at right angles. The magnification of the large refractor being considerable, the field of view embraces only a small part of the sky; therefore, on using this to find an object it is brought into the field with much difficulty. The field of the

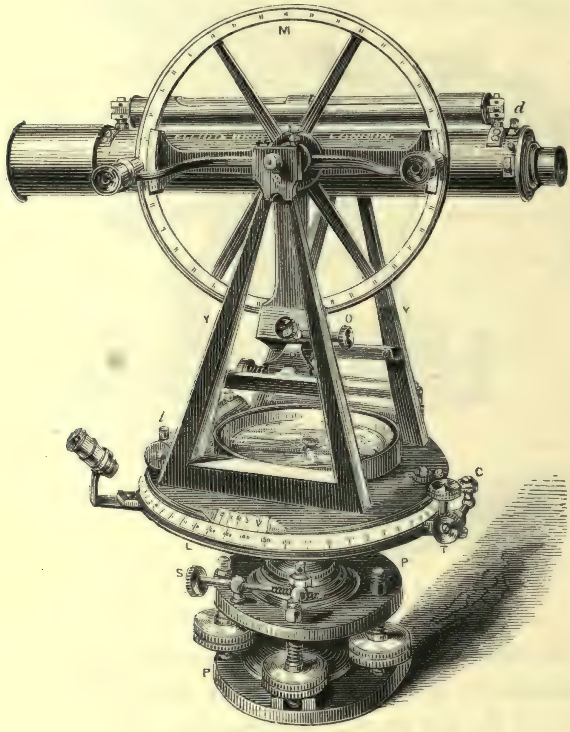

FIG. 197.—Theodolite (another form).

finder being comparatively large, the object is easily found, and by bringing the object to the point where the threads cross, the object observed, or at any rate its central part, is then in the field of the principal refractor. The field of view of the large telescope itself has a system of movable threads at the common focus of the object-glass and eye-piece, *i.e.*, where the image of the object falls, so that

they can be observed at the same time, and measures of the object can be taken.

The long focus instruments in astronomical observatories are so heavy that their manipulation would be difficult unless special

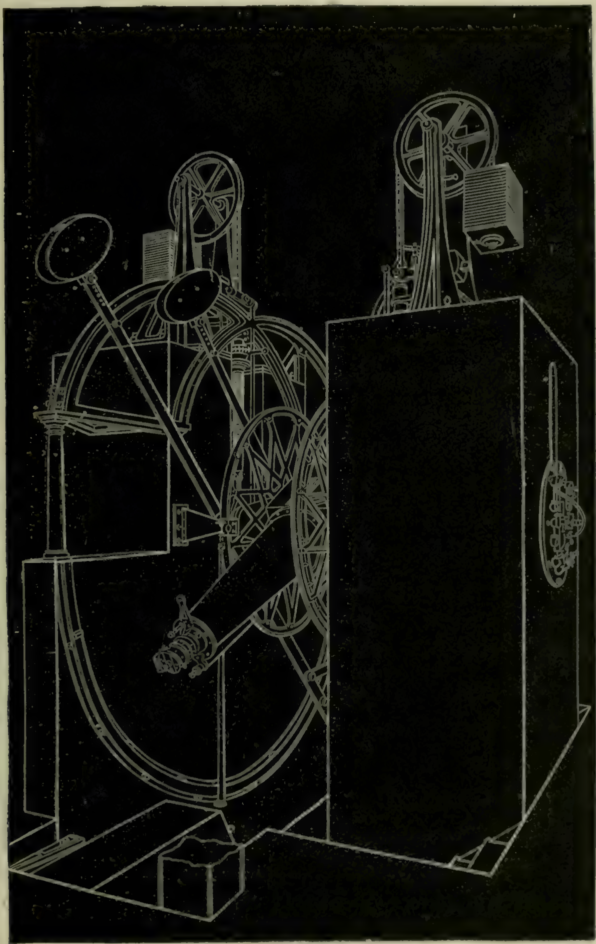

FIG. 198.—Perspective view of the transit circle at Greenwich.

arrangements were adopted. A complicated and carefully-balanced mounting, called the equatorial mounting (see Plate XI.), is therefore used, and by means of wheel-work and driving-clocks all the necessary

motions can be given, so that the object can be kept in the field of view for a long time.

From what we have already said of the magnifying power of an astronomical refractor, it follows that it depends for the same instrument, or rather for the same object-glass, on the eye-piece. And indeed, the same object-glass gives various magnifying powers when different eye-pieces, with shorter or longer focus, are used. Theoretically speaking, the power of a telescope would be unlimited, did not other considerations, on which we will say a few words, come in.

The quality and power of a telescope depend principally on the object-glass. In the first place it is indispensable that the material of which it is composed be as pure as possible, and that the glass be free from bubbles and striæ.

The grinding and polishing of the surface are also of great importance, and it is on their perfection that the sharpness of the images which are formed at the focus depends.

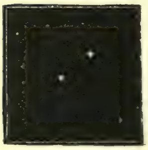

FIG. 199.—A portion of the constellation Gemini, seen with the naked eye.

Now, with equal perfection in the above qualities, the object-glass with the greatest diameter, and the longest focal length will allow the greatest magnification. The brightness of the virtual image depends in the first place on the brightness of the real image, and consequently on the quantity of luminous rays which contribute to form it. This depends upon the size or aperture of the object-glass. As the magnifying power of the eye-piece spreads the light over a larger space, the virtual image is weakened and rendered indistinct in proportion as this magnification is greater, unless the rays proceed from luminous points of imperceptible dimensions, like the stars. In this case the loss of light due to magnification is slight, and the brilliancy obtained is in the ratio of the squares of the aperture of the object-glass and the pupil of the eye. In this manner with a lens of large aperture, the number of the stars seen in a limited space of the sky is increased considerably, as represented in Figs. 199 and 200. The one shows a portion of the heavens in the constellation *Gemini*, in which the stars seen with the naked eye are seven in number; by using a lens of 27 centimetres aperture M. Chacormac has counted 3,205. If we allow 6 millimetres for the

aperture of the pupil, the light is increased in the ratio of 36 to 72,900 or 1 to 2,025, the absorption of light by the lens being neglected. This also explains the possibility of distinguishing in the daylight with the telescope, stars which can only be seen with the naked eye in the evening or during the night.

Bodies not luminous of themselves, such as the moon and planets, appear in the telescope much less brilliant than with the naked eye,

FIG. 200.—The same portion of the heavens seen with a telescope of 27 centimetres aperture.

and it therefore follows that the magnifying power is limited for a given aperture.

Astronomical instruments require such perfection in their manufacture as makes them costly acquisitions. The object-glass requires, besides purity of material, a long and difficult process of grinding and polishing, without which the sharpness and achromatism of the

images cannot be obtained. It is also necessary to subject them to tests by experienced observers. Generally they are tested by certain celestial objects difficult of observation—certain double stars among them, other objects may be seen moderately well through nearly all instruments, and no glass is so bad that the moon cannot be looked at with pleasure. But high powers must be avoided except for stars. A medium power which gives clearness and sharpness is preferable to extreme ones, which are too often applied to instruments without any real use.

Among the most noted and powerful astronomical refractors known in the present day, we may notice those constructed by Messrs. Cooke and Sons of York and by Alvan Clarke of America, of 25 and 26 inches aperture respectively. The former belongs to Mr. R. S. Newall of Gateshead, the latter is at work in the Naval Observatory at Washington.

§ III.—The Erecting Telescope.

Kepler made the theoretical discovery of the astronomical telescope, with convergent eye-piece, but the great astronomer did not realize

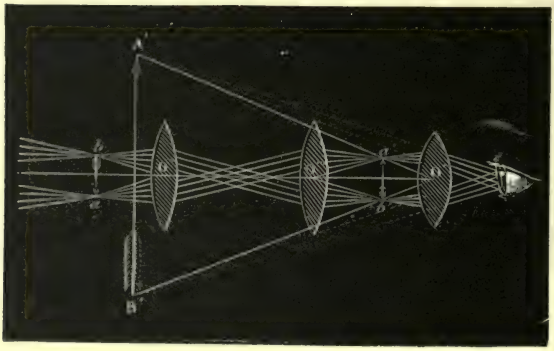

Fig. 201.—Path of the luminous rays in the erecting telescope.

his conception; Father Scheiner it was who first constructed a telescope of this kind, which by degrees superseded Galileo's. A short time after, Reita invented the terrestrial telescope, which only differs from the astronomical in the arrangement of the eye-piece. By

using two convergent lenses of the same focus, $o''o'''$, placed between the system o' of the astronomical eye-piece and the real image of the object-glass, *a*, *b*, the virtual image is made erect, as it is easy to see by following the path of the rays in Fig. 201. We see therefore that the eye-piece system of the erecting or terrestrial telescope is formed of three or four lenses.

The advantage of this combination is that the images are erect, which for terrestrial objects is necessary. The inconvenience lies in the feebleness of the light. The light absorbed and reflected by the passage through two extra lenses is the cause of this.

In the present day such telescopes are made of all dimensions and very varied powers, both for useful applications as well as for amusement. Before the invention of the electric telegraph, those who worked the aerial telegraphs used telescopes to see the signals clearly, with apertures of 8 or 9 centimetres and 2·50m. focal distance. Sailors use similar instruments but of smaller dimensions, on account of being more convenient to handle on board ship. Night glasses, of which they make frequent use, are either telescopes with a simple eye-piece like astronomical refractors, or with an object-glass of large diameter in order to give the greatest possible light and to allow of observation when the light is dim. For houses in the country more powerful glasses are constructed, as they can be fixed on stands of various forms; they are furnished with a number of eye-pieces, some terrestrial and others astronomical, of different magnifying powers, and with these astronomical amateurs can make many interesting observations.

§ IV.—Reflecting Telescopes.

A reflector, or catadioptric telescope, differs from a refractor in this way; the object-glass is replaced by a concave mirror, which gives a real image of the object, situated at its principal focus when the object is at an infinite distance. By adjusting the eye-piece properly for the examination of this image, the magnification wished for can be obtained as in the refractor. The substitution of a mirror for the lens was suggested by Zucchi in 1616. But Gregory, an English astronomer, deserves the credit of the first effective application, and,

one may say, of the invention of this telescope. As will be seen further on, in his form of instrument the image of the object magnified by the aid of the eye-piece is formed after double reflection, first, by a large and then by a small concave mirror, whence considerable loss of light results. Newton proposed a different arrangement, in which the reflection took place on two mirrors, one of them being a plane one; and lastly, Sir W. Herschel completely did away with the second reflection in the telescopes of large apertures which are named after him. We will begin with this last system, the most simple of all.

A concave mirror M, arranged at the bottom end of the tube, receives the rays coming from the object AB, and by reflection gives rise to the

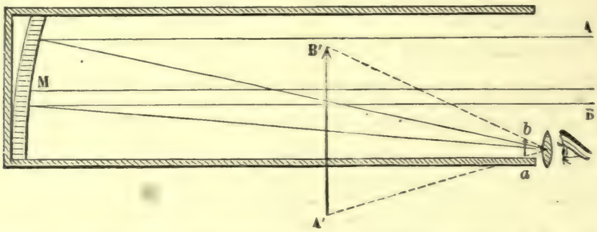

FIG. 202.—Principle and arrangement of Sir W. Herschel's (front view) telescope.

formation of a reversed aerial or real image, *b*, *a*. By using the eye-piece 0, arranged in front of the principal focus of the mirror on the lower edge of the tube, the eye sees the image B′A′ magnified, but reversed. This arrangement is only possible in telescopes with a mirror of large aperture, so that the head of the observer, who turns his back to the portion of the heavens observed, does not to any large extent intercept the rays falling on the mirror. For this reason a position slightly inclined to the axis of the tube is given to the mirror. In a very large telescope the portion of the head which encroaches on the aperture of the tube is but a small fraction of the surface of the mirror; this would not be the case in a telescope of small dimensions. Telescopes of this kind are known as front-view telescopes, a name given to them by Sir W. Herschel himself. The largest made by the illustrious astronomer of Slough on this model is that represented in Fig. 203. It was 39 feet 4 inches

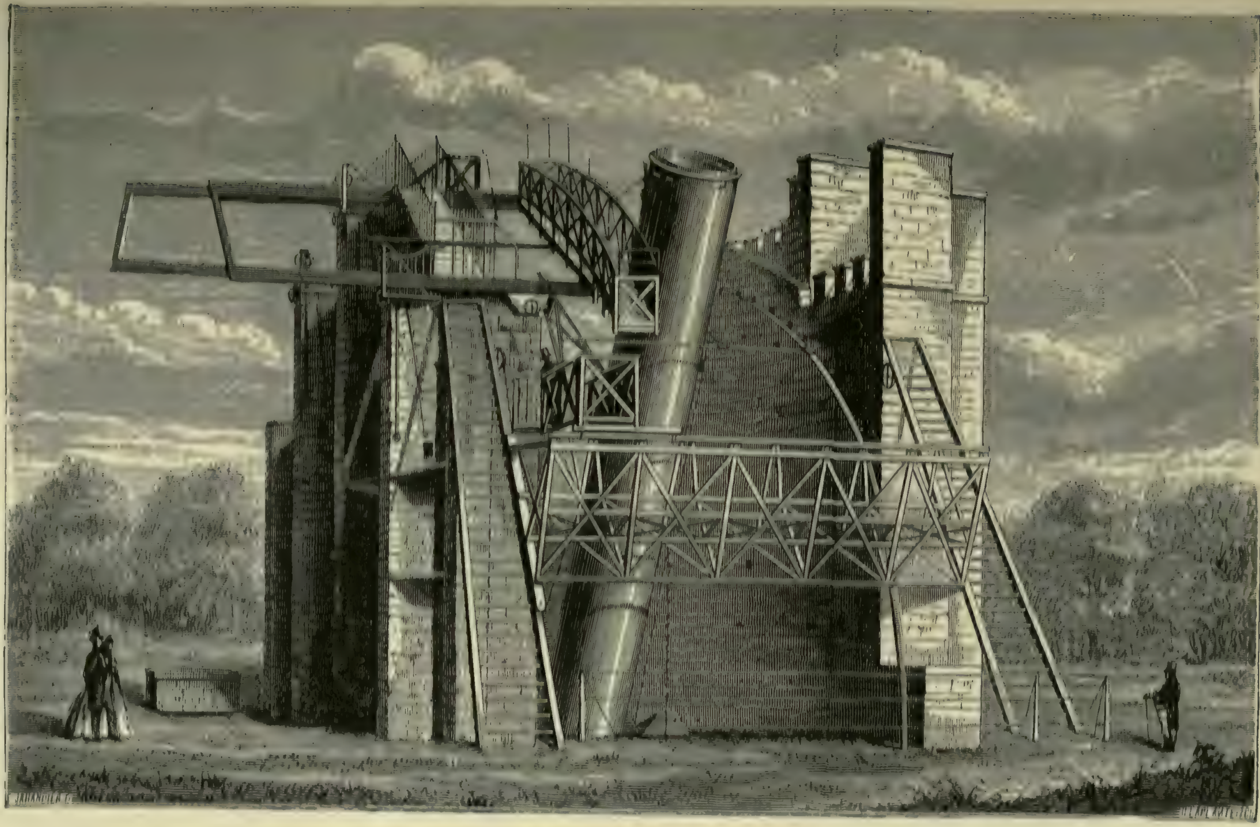

PLATE X.—THE ROSSE REFLECTOR.

in length (13 metres), and the mirror had a diameter of 4 feet 10 inches (1·47m). Arago remarked, "Such dimensions are enormous, compared with those of telescopes made up to the present time. Nevertheless, they would appear very insignificant to the people who were told of an imaginary ball given inside the Slough telescope. The originators of this story confounded the astronomer Herschel, with the brewer Meux,—a cylinder in which the shortest man could scarcely stand, with the large wooden vats, large as houses, in which beer is made and kept."

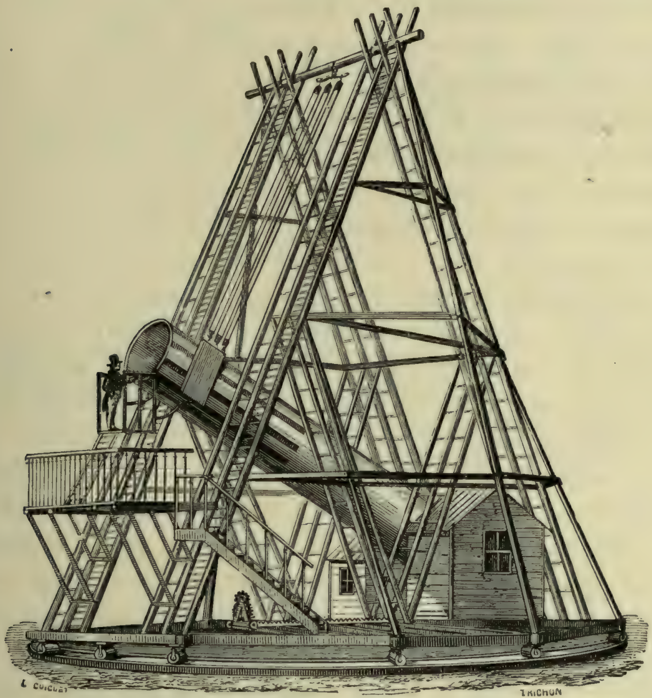

FIG. 203.—Sir W. Herschel's large telescope (front view) at the Slough observatory.

This telescope with its immense weight was, as may be imagined, not easy to move. A very ingenious combination of masts, pulleys and cords, and the continual help of two men, besides an assistant in charge to take the time, were required for working it. More than this, observations with such powerful instruments necessitate a sky of the greatest purity, without which the magnification of the irregularities due to the atmosphere deforms the images and causes

them to be indistinct. Herschel found that in England there were not more than one hundred hours during which the sky could be studied usefully with his largest telescope, using a magnifying power 1000 times. This conclusion drove the celebrated astronomer to acknowledge that to take with his instrument a survey of the heavens, with the field only one instant on each point of the expanse, would require no less than eight hundred years.

The telescope which was erected by Lord Rosse in his park of Parsonstown, in Ireland, is still more colossal than Herschel's. The metal mirror of 1·83 metres (6 ft.) in diameter and about 17 metres (60 feet) focal length, alone weighs nearly 4000 kilogrammes. The total weight of the optical apparatus, tube and mirror, is not less than 10,400 kilogrammes. It has been stated that a magnifying power of 6000 can be employed. But such a power is only applicable to observations of very luminous objects, such as stars or star-clusters. Researches in sidereal astronomy have been carried on with the greatest success by means of this magnificent instrument. In a companion volume to this, *The Heavens,* numerous examples of stellar clusters and nebulæ, observed mostly at Parsonstown with the large telescope which is represented in Plate X. are given.

We have now come to Gregory's form of telescope. At the principal focus of the larger mirror, placed at the eye-end of the tube, a reversed image of the celestial object AB is formed. In front of the great mirror and on the same axis, a small concave mirror M with its reflecting surface turned towards the larger mirror is arranged. The real image is formed by the larger mirror in front of this small one, which then forms a second and enlarged image doubly reversed, which is magnified by the eye-piece.

To give an outlet to the pencils of light, the large mirror is pierced with an opening at its centre, near and behind which is fixed the eye-piece tube, so that the observer has the eye turned directly towards the portion of the sky observed, as in the refractor. The light is reduced first by the aperture made in the centre, which diminishes the surface, but particularly by the second reflection on the surface of the small mirror. This is the inconvenience of Gregory's form; the principal advantage of it is the facility with which observations are made, but this does not always dispense with the necessity of a finder.

In Gregory's telescopes, the magnified image is erect; this instrument may therefore be used as a terrestrial telescope. By the use of a rod outside, the small mirror can be moved so as to obtain accurate focus, the eye-piece being fixed. This adjustment is also necessary when an observation is first taken on a celestial object and then on a terrestrial one more or less distant from the observer.

Cassegrain's telescope is arranged in a somewhat similar manner. It has the same inconveniences and some advantages. In this construction, the small mirror, which is convex, is placed between the large mirror and the image.

It remains for us to speak of the form suggested by Newton, Fig. 206. The mirror *m* which receives the rays from the object mirror M is placed, as in Cassegrain's, in front of the principal

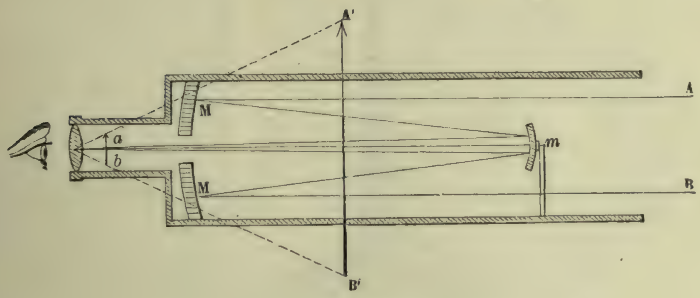

FIG. 204.—Principle and arrangement of Gregory's telescope.

focus where the real image is formed. But it is a plane mirror inclined at an angle of 45°, so that it deviates the beam in a direction at right angles to the axis of the instrument. An aperture is made in the side of the tube, and the eye-piece tube is placed in it to examine the magnified image.

Instead of a plane mirror, a rectangular prism may be used, the rays are reflected to the eye-piece by the back surface at the angle of total reflection.

Sir W. Herschel constructed a number of telescopes for his own observations; he ground and polished the mirrors, and was most skilful in these long and delicate operations.

The following are some interesting details borrowed from the excellent notice published by Arago on the labours of the great astronomer at Slough :—

"Before finding direct and certain methods of giving the necessary images to the mirror, it was requisite that Sir W. Herschel should win his way by degrees like his predecessors. His trials were directed in such a way that he did not take a step backwards. In his

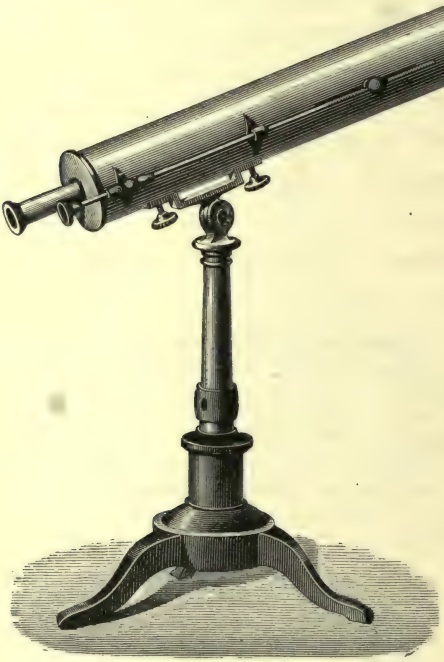

FIG. 205.—Gregory's telescope.

method of work, according to an old adage, '*Le mieux n'était jamais l'ennemi du bien.*' When Herschel undertook the construction of a telescope, he cast[1] and worked several mirrors at a time—ten, for instance. The one of these mirrors with which observations made

[1] The metal of which the mirrors of telescopes are made is generally composed of 67 parts of copper and 33 of tin. This alloy is of a yellowish tint, and is susceptible of a beautiful polish. Sometimes small proportions of brass, silver, arsenic, and also platinum are added.

PLATE XI.—THE NEW TELESCOPE OF THE PARIS OBSERVATORY.
(From a Photograph.)

under favourable circumstances gave the best results was placed in the first rank and put aside, and the nine others were worked at. When one of these became better than the first, it took its place, until, in turn, another took the lead, and so on. It is curious to learn on what a large scale these experiments were carried on even at a time when Herschel was only a simple amateur astronomer in the city of Bath. He made as many as 200 Newtonian mirrors of 7 feet focus (2·13m), 150 mirrors of 10 feet focus (3·05m.), and about 24 mirrors of 20 feet (6·096m).

" 'Each time Herschel undertook to polish the mirror of a telescope,' says Lalande, 'he worked continuously for ten, twelve, and fourteen hours. He never left it an instant, not even to eat, and received from his sister's hand the nourishment without which it would have

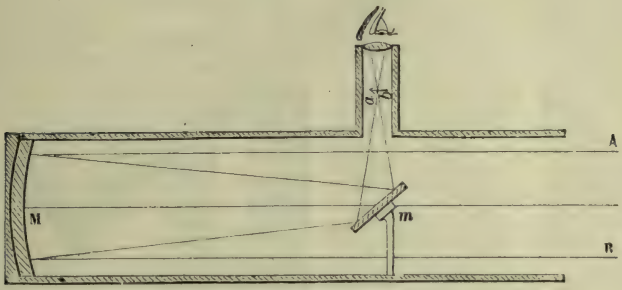

FIG. 206.—Principle and arrangement of Newton's telescope.

been impossible to undergo such long fatigue. Herschel would not leave his work for any consideration; according to him, this would have spoilt it.' "

Telescopes with metal mirrors have serious inconveniences; besides the enormous weight of the mirror, when the aperture is considerable, they have the defect of requiring frequent polishing, as they tarnish under the influence of atmospheric moisture. The polishing itself is a delicate operation, as it may change the curve of the mirror.

Foucault succeeded in diminishing considerably with equal apertures the weight of the mirror, and rendering the curvature nearly unchangeable—great advantages in addition to the absence of chromatic aberration.

To accomplish this, he substituted glass mirrors for metal ones, and rendered them free from spherical aberration by working them by a special method until they had obtained a nearly perfect parabolic form. He also increased the reflecting power of the mirror by silvering the surface. By using a solution of ammoniacal nitrate of silver in alcohol, it is possible, at the ordinary temperature,

FIG. 207.—Léon Foucault's telescope with silver mirror (Newtonian system).

to cover the surface with a thick metallic film, which can be easily renewed without at all damaging the geometric form of the mirror.

An instrument of this kind, arranged after the Newtonian system and mounted equatorially, so that the diurnal movement of a heavenly body may be followed, has recently been constructed at

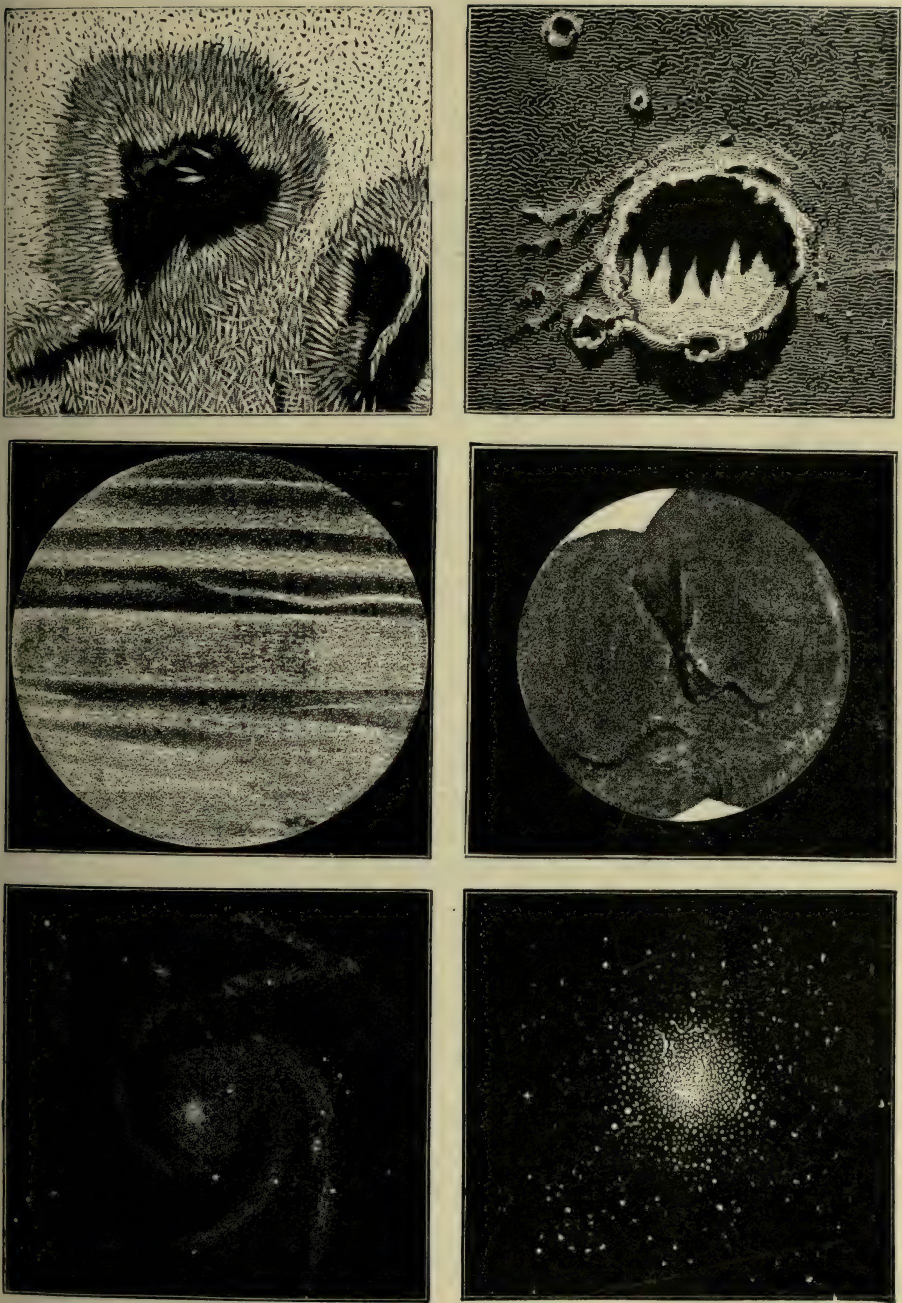

PLATE XII.—THE TELESCOPE APPLIED TO THE STUDY OF THE HEAVENS.

1. Sun-spots.—2. Lunar craters.—3. Jupiter with his belts.—4. Spots, poles, continents and seas in Mars.—5. A nebula.—6. A Star-cluster.

the observatory of Paris. (See Plate XI.) The mirror is 1·20 metres (4 feet) in diameter.

The illustration which we give represents the telescope in a position for observation. The wheeled hut under which it usually stands, a sort of waggon seven metres high by nine long and five broad, is pushed back towards the north along double rails. The observing staircase has been fitted to a second system of rails, which permits it to circulate all round the foot of the telescope, at the same time that it can turn upon itself, for the purpose of placing the observer, standing either on the steps or on the upper balcony, within reach of the eye-piece. This eye-piece itself may be turned round the end of the telescope into whatever position is most easily accessible to the observer.

The tube of the telescope, 7·30 metres in length, consists of a central cylinder, to the extremities of which are fastened two tubes 3 metres long, consisting of four rings of wrought iron wrought together by twelve longitudinal bars also of iron. The whole is lined with small sheets of steel plate. The total weight is about 2400 kilogrammes. At the lower extremity is fixed the cell which holds the mirror; at the other end a circle, movable on the open mouth of the telescope, carries at its centre a plane mirror, which throws to the side the cone of rays reflected by the great mirror.

The weight of the mirror in its barrel is about 800 kilogrammes; the eye-piece and its accessories have the same weight.

Silver-mirror telescopes are made of small dimensions, which magnify 60 to 200 times. Fig. 207 represents one of this model, with the mirror 10 centimetres in diameter and only 60 centimetres focal distance. With a similar instrument astronomical amateurs may divide numerous double stars, observe Jupiter's satellites, Saturn's rings, sun spots, and distinguish very interesting details in the lunar mountains. If we wish to form an exact idea of the important services that the invention of telescopes has rendered for the last two centuries to the science of observation, and particularly to the astronomer, it is necessary to read the history of these sciences themselves; at each page one is arrested in wonder before the grand results.

We have collected in Plate XII. a few examples of the details which the telescope gives us of the structure of the sun,

moon, and planets, and of those more distant masses of matter, star-clusters and nebulæ.

But it is not the curiosities or the wonders of the heavens alone which we must pass under review; it is not only the depths of infinite space where the systems of stars and nebulæ shine that must be explored. We must insist above and before all upon the progress which the use of these instruments has rendered possible in exact astronomy, and in the sublime theories which now explain all the laws of the heavenly movements by considering the entire universe as a system of bodies and forces reacting one against the other—a system offering to geometry, on an infinite scale, the most admirable applications of the theories of rational mechanics.

CHAPTER V.

THE STEREOSCOPE.

§ I.—Vision in Relief.—Wheatstone's Reflecting Stereoscope.

When we examine, with the naked eye, a landscape, tree, or monument, we have not simply the sensation of a picture, that is to say, of a flat representation of the objects severally portrayed on our retina. We have, besides this, a clear and lively impression of the *relief* of the objects, that is, of their unequal distances, and the intervals which separate them; the depth of space is an intuitive sensation resulting from the normal phenomenon of vision.

Why do paintings never produce the same impressions as the objects themselves, whatever may be the merit of the artist who has created them, however faithful the perspective, the contour, the colouring of the objects, and the lights and shades? It is a great and rare talent which throws atmosphere into a picture, depth into a landscape; but even when the artist has succeeded, the idea of relief falls very short of nature.

It was long before this difference between a flat representation and the real view—vision in relief—was accounted for. There is, however, a very simple method of solving the problem. If, after observing a foreground with both eyes we examine it with one, either the right or left, the sensation of relievo, of depth, disappears; or at least it is to a great extent diminished. The landscape itself seems a painting in which the different lines are confused together. This difference between ordinary or binocular and monocular vision. is almost imperceptible for distant objects; it is greater in proportion as the objects are nearer; it attains a maximum for those in the foreground.

This first point proved—What is the result when we examine an object in relief with one eye? This may be tested in the simplest manner. Let us take for example a cube die (Fig. 208), or a quadrangular pyramid. Let us place them both in a vertical plane passing between the two eyes, and look at each with both eyes together: the two figures A and B will represent the two objects seen in that way. If we close the left eye the aspect will change. The right lateral surface of the die A′ will be more visible, while the left will have disappeared; the lateral surfaces of the pyramid B′ will also appear of unequal size. If we now close the right eye, an opposite effect will be produced as shown at A″ and B″. We may make a thousand

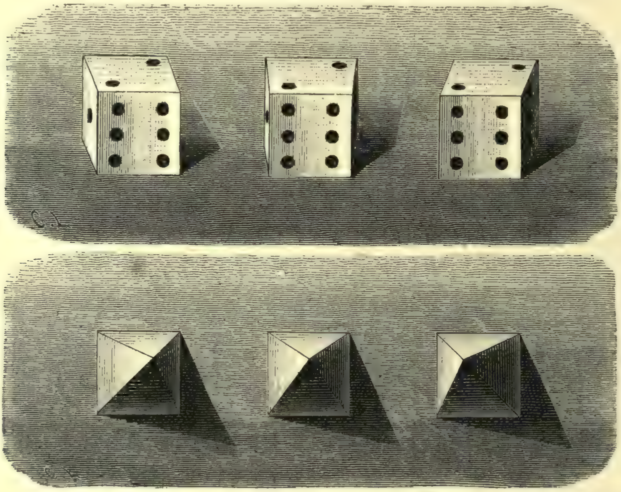

FIG. 208.—Difference between monocular and binocular vision.

similar experiments on near or distant objects. We shall find that the sight, with the right eye alone, discovers parts which remain hidden when we use only the left eye. From this we conclude that a different picture of the same object is painted on each retina, right and left, so that we might expect as a result of binocular vision a double picture. But experience proves that this is not the case, and that these two pictures are so superposed as only to give one distinct impression in which the different parts of the two pictures are united. Complete or normal vision envelops, so to speak, objects in relief, and the more so the nearer they are.

If to this we add the necessity of accommodating the eye for accurate vision according to distance we shall understand the difference, already explained, between the impression produced by the binocular sight of real objects and the impression made by the most accurate picture representing them. In the case of the picture similar images are painted on each retina, and vision in relief, stereoscopic vision (στερεός, solid, and σκοπεῖν, to see) is impossible.

It is to the analysis of these phenomena that we owe the invention of the optical instruments known as stereoscopes. A celebrated English natural philosopher, the late Sir Charles Wheatstone, was the first who had this idea, and he realized it in the little apparatus which bears the name of reflecting stereoscope.

This very simple arrangement is as follows:—M and M′ are two vertical mirrors placed at right angles to each other on a rectangular

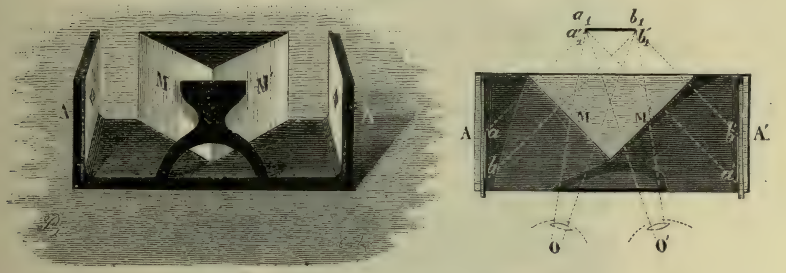

FIG. 209.—Wheatstone's reflecting stereoscope.

board, so as to form with the edges of this board angles of 45°. Two lateral uprights A and A′ are furnished with cross-head guides, and can thus receive two images of the same object, of the same view. It is evident that these images will be reproduced reflected by each mirror, and form two vertical images, apparently placed behind each mirror symmetrically with regard to the actual object. Thus a b will produce the image a_1 b_1 the two similar points a' b' of the object on the right will form an image a'_1 b'_1 which will be placed exactly over the first.

If then the two eyes OO′ are placed in front of the mirrors, and if by means of a diaphragm each is prevented from seeing the image produced on the other mirror, the two images a_1 b_1 and a'_1 b'_1 will

seem to come from the same point in space; they will be depicted on the retina of each eye, as would happen in the case of a real object. Now, what is required to produce complete identity between

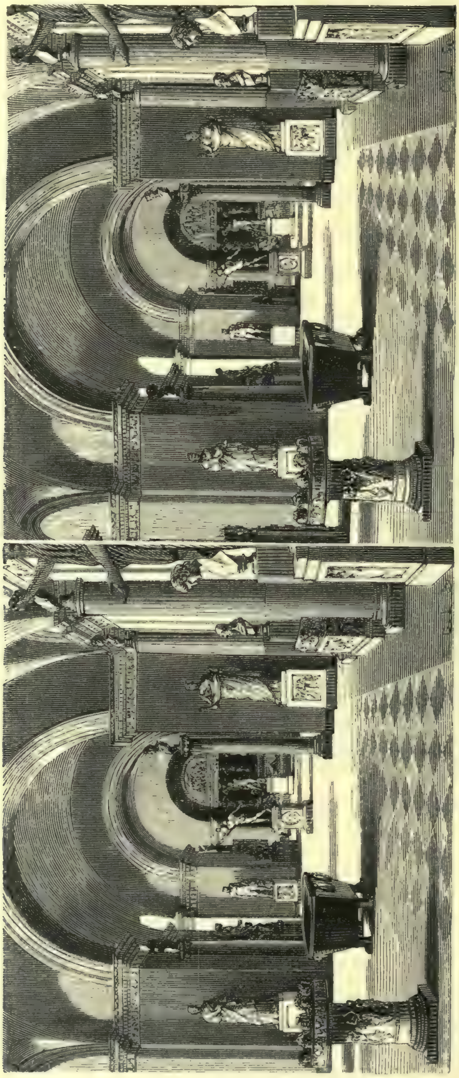

FIG. 210. Stereoscopic proofs. Facsimile of a photograph representing one of the rooms in the Louvre.

the phenomena of vision in the case of the real object in relief, and the same object in a picture? This,—that the two separate views be precisely those received by each eye individually examining them

from the same point of view. This is an essential condition of stereoscopic vision ; if it be realized, the superposition of the two images will occur as in nature. We shall have before us, not a flat representation, but a vision in relief, more life-like and vivid, in proportion as the reproduction of the pictures with their details of light and shade is faithful. If they are not coloured one may fancy one sees objects in marble, a sculptured reproduction of nature.

Wheatstone's reflecting stereoscope was very soon modified, or at least the principle on which it was constructed has been the basis of a more handy and more perfect instrument, the invention of Sir David Brewster, and this was still further perfected by two French opticians, Soleil and Dubosq.

But before describing the refracting stereoscope, a simple process which enables us to realise the stereoscopic vision of images may be referred to. We require, for this, to place two drawings side by side, as is done in Fig. 210, and to interpose a diaphragm, a bit of paper or card-board, on the middle line between the two eyes. After some seconds the two images are superposed, and stand out in relief. Still it is a fatiguing exercise for the eyes, and stereoscopes, as now constructed, have a marked advantage over this elementary stereoscopic process.

§ II.—Brewster's Refracting Stereoscope—Helmholtz's Stereoscope—Pseudoscope.

We now arrive at Brewster's stereoscope. Here, Fig. 211, the two images are not examined by reflection on two mirrors, but directly, by placing the eyes before two lenses, two portions A A′ of a prism or a converging lens. From similar points, C C′, on each stereoscopic view a ray of light proceeds, which is refracted by each prism, and gives rise to an image in the eye which is formed at the same point, beyond the plane of the drawing, at C. The same thing happens with all the corresponding parts of the picture, so that the two stereoscopic views are depicted simultaneously at *a*, *b*, the right view on the right retina, the left on the left retina. Perfect vision in relief is the result, especially if the pictures are

exact photographic reproductions, carefully taken from well chosen positions, and with favourable conditions of light.

It is important that the two images be equally illuminated. This is secured by holding the stereoscope so that the light falls equally on both pictures through the opening arranged for the purpose. If the photographs are on glass, the apparatus may be placed opposite the daylight or lamplight. In this case the back of the stereoscope is provided with a piece of ground glass, which evenly distributes the light, and intercepts the vision of exterior objects.

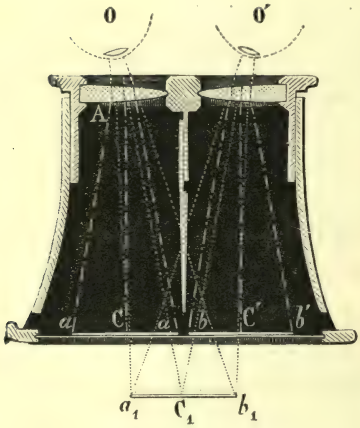

FIG. 211.—Refracting stereoscope: section.

The stereoscope not only gives the impression of relief, it also produces the effect of converging lenses or magnifying glasses, for it magnifies objects, and consequently facilitates the accurate study of details.

To increase these effects the prisms are replaced by combinations of lenses, as represented in section on Fig. 213. This form was arranged by Helmholtz. Besides the alteration of the eye-pieces, it is distinguished by a special mechanism, by which the distance of the two eye-pieces can be regulated, and the distance of the eyes or the lenses from the stereoscopic pictures can be increased or diminished at will. This arrangement is useful, because stereoscopic images are not always so placed that the distance of the corresponding points

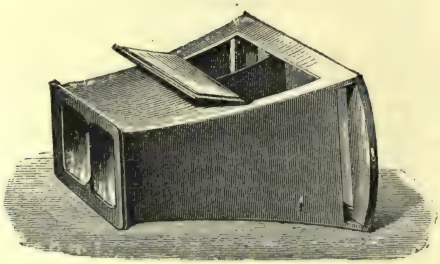

FIG. 212.—Refracting stereoscope: external view.

coincides with that of the eyes, or that their heights are equal above the base-line. The eye-pieces may be shifted, by help of the screws, either laterally or up and down. The movement of these draw-tubes is intended to bring the photographs into focus.

Monuments, figures, in short every salient object is depicted in the stereoscope with a wonderful fidelity of relief, which causes complete illusion. But, as Helmholtz justly remarks,[1] "the advantage of stereoscopic vision is most strongly felt in examining reproductions of those objects which cannot be successfully represented in ordinary

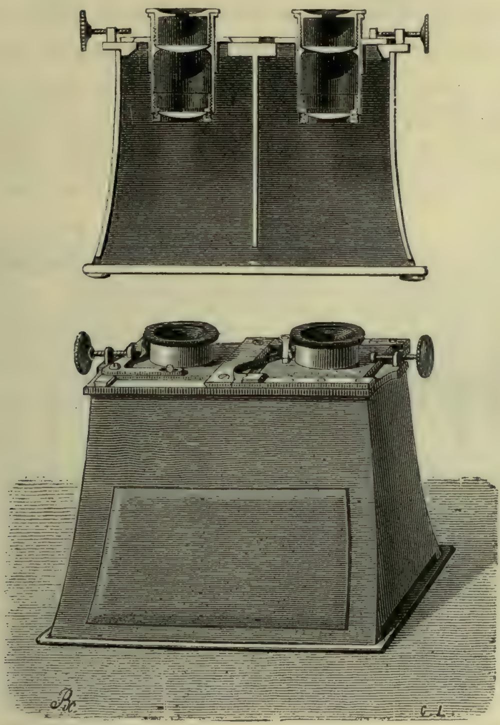

FIG. 213.—Helmholtz's stereoscope.

drawing or painting; such as irregular rocks, blocks of ice, microscopic objects, animals, forests, &c. Glaciers especially, with their deep fissures illuminated transparently through the thickness of the ice,

[1] *Physiological Optics.*

produce a surprising effect in the stereoscope. The single image generally gives the idea of a confused agglomeration of grey patches, whereas the stereoscopic combination brings out in the most palpable manner the forms of the blocks, as well as the effects of transmitted and reflected light. The primary difficulty lies in accurately rendering such irregular forms as blocks of ice when simply illuminated by incident light; this is increased by the light transmitted by the ice, which completely alters the ordinary effects of shadows. The stereoscopic representation of brilliant objects, such as water covered with light rippling waves, produces very wonderful effects."

Some stereoscopes are so constructed that the light proceeding from the two pictures, before passing through the prisms or eye-lenses, is totally reflected inside two rectangular prisms, whose reflecting surface is parallel to the direction of the light which reaches the eyes. In this arrangement, the two images are seen with the symmetry of nature; they are superposed, but in such a way that what is on the right side is seen on the left, and *vice versâ*. The images are thus inverted; and, consequently, the result is such that hollow objects appear in relief, and the reliefs appear hollow.

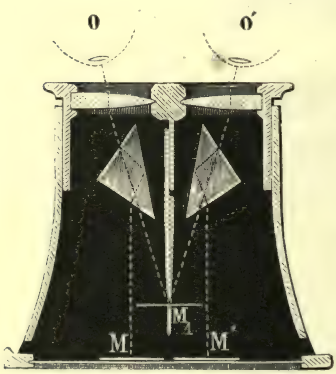

FIG. 214.—The pseudoscope.

Nevertheless the shadows sometimes dispel this illusion, as do other circumstances which assist the perspective and shadows in giving the vision the feeling of relief. An example will show us the reason for the change of position of the images in this arrangement of the stereoscope, which is called the pseudoscope.

Let us consider the case of a truncated pyramid seen from above, and let us suppose that the oblique light produces no shadow; there will only be the various degrees of brightness in the lateral surfaces.

The two stereoscopic views should be arranged as in figures A' and A'', and then they will give, in the stereoscope, the impression of relief. But in the pseudoscope the two drawings give symmetrical

images, and produce the effect which would be given by the two stereoscopic views A′ and A″. Now these images, which are superposed by the effect of the apparatus, are views of a pyramid similar to

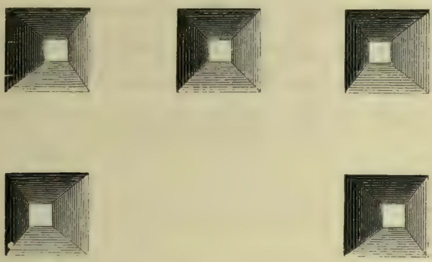

FIG. 215.—Direct and inverse stereoscopic vision: relief and hollow.

the first one, illuminated by the same light, but appearing hollow instead of in relief, since in the right eye the left side is enlarged by the perspective, and the contrary effect is felt in the left eye. The

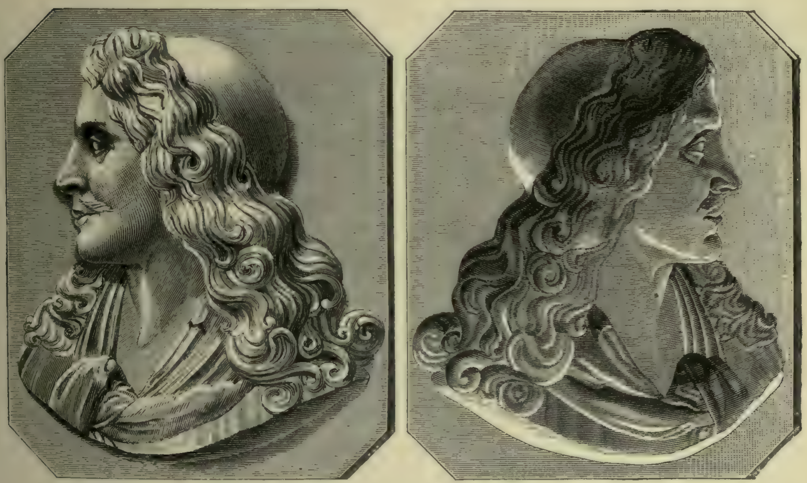

FIG. 216.—Pseudoscopic vision: medallion of Molière.

effect of the pseudoscope is produced naturally when we are looking at drawings in which the shadows are well defined, as in medallions. An object of this kind will be seen now in relief, now concave. One or other sensation is easily obtained at will, if care is taken to place the drawing in such a position with regard to the light that the shadows

come on the side where they would actually be found, if the drawing were in reality in relief or the reverse.

The beautiful *facsimile* of a lunar photograph, which we owe to the courtesy of M. Warren Delarue, and which forms the eleventh plate of the fourth edition of *The Heavens,* is well fitted for the experiment of which we speak. The volcanic craters of the lunar mountains appear in one case like the hollow shafts of a cone, which they really are, and, in the other aspect, they resemble inverted bubbles.

CHAPTER VI.

PHOTOGRAPHY.

§ I.—First Attempts at Fixing the Images Produced in the Camera Obscura—Discoveries of Niepce and Daguerre.

When rays of light, proceeding from an object, are received on a white surface, at the focus of the converging lens of the camera obscura, a marvellously faithful image is produced. It is a true picture in miniature of the landscape in view, with all its shades of light and colour and all the most minute details; but it is a fleeting image, quite ideal, so to speak, consisting only in the movement of the waves of light. We close the opening which gives access to those waves, and, instantly, the image vanishes.

More than one observer, from Porta, the inventor of the camera obscura, to Niepce and Daguerre, the inventors of photography, must have desired to retain and fix these images, and thus to enlist nature herself as coadjutor with art in drawing and painting. What was required to produce this result? The knowledge of another property which the rays possess, of acting chemically on certain substances, and thus leaving a visible trace of their action, the power of which is in proportion to the intensity of the rays. In 1770, Scheele had discovered the property possessed by chloride of silver of turning black under the influence of light, or rather he had studied afresh this action known to the alchemists of old. It was by utilising this property that an able French naturalist succeeded, in the early part of this century, in obtaining sketches by the action of light. We do not know how he obtained them, but doubtless the process employed by him had some analogy with that described by Arago in the following terms, and by which negative proofs of a picture may be

obtained:—"Place a picture on some paper coated with chloride of silver, and expose the whole to the sunlight, the picture uppermost. The dark portions will stop the rays; the corresponding parts of the coating, those touched and covered by these black portions, will retain their primitive whiteness. On the contrary, where the paper on which the picture is printed has retained its semi-transparency, the solar light will pass and blacken the silver layer. The result will be a copy like the original in form, but with a reversal of all the tints; the lights will be found dark, and *vice versâ.*" Unfortunately these negatives, like Charles's sketches, were not permanent, because the light, continuing to act on the parts not attacked at first, eventually covered the paper coated with chloride with one uniform tint of black. In 1802, Wedgwood succeeded in copying engravings, and in reproducing, on white leather and on paper coated with chloride or nitrate of silver, the designs on the painted windows of churches; but he did not think it possible to apply his process to the reproduction of the images produced in the camera obscura. At the same time Sir H. Davy succeeded in obtaining pictures of minute objects by placing them at a short distance from the lens of the solar microscope. These attempts were however incomplete, in the sense that neither Wedgwood nor Davy discovered the means of fixing the images obtained, that is, of preventing their disappearance in sunlight. About twelve years later, Nicéphore Niepce of Châlons-sur-Saône, who devoted his leisure to scientific studies, also attacked this problem of the photogenic reproduction of the images seen in the camera obscura. After numerous unsuccessful efforts, he was obliged to give up the attempt to obtain views from nature, monuments, or scenery, on account of the great length of time required by the materials he used to receive the action of light. Until 1829, the time of his association with Daguerre, Niepce confined himself to the photographic copying of engravings; but he had the satisfaction of succeeding completely in fixing the images, a problem unsolved by Charles, Wedgwood, and Sir H. Davy. We will describe his process in a few words.

To a sheet of copper, covered with silver and perfectly polished, he applied, with the aid of a stopple, a varnish composed of bitumen dissolved in oil of lavender. The plate, after being gently warmed, was then found to be covered uniformly with a whitish layer of bitumen

adhering to its surface. Placed in this state in the focus of the lens of the camera obscura, it showed after a little time faint lineaments of the picture. To make these features more discernible Niepce formed the idea of plunging the plate into a solution of oil of lavender and petroleum; and he discovered that "those parts of the film *which had been exposed to the light* remained almost intact, while the others dissolved rapidly and left the metal bare. After having washed the plate with water the image was visible, the lights and shadows being correctly shown—in a word, *a positive copy* of the picture had been obtained. The lights were formed by the diffused light proceeding from the whitish, unpolished matter of the bitumen; the shadows by the polished uncovered parts of the silver; it must however be understood, that this resulted when the pure parts of that metal were so situated that they could not send any bright light to the eye by specular reflection. The half-tints, where they existed, resulted from those parts of the varnish which a partial penetration of the solvent had rendered less dense than the parts which had remained intact." (Arago.) Daguerre began by perfecting Niepce's method: he succeeded in reducing the time of exposure of the plate to the light; but even then necessitating an action of several hours. We can understand, therefore, that, even with these improvements, it was well nigh impossible to obtain satisfactory reproductions of images in the camera, as objects illuminated by the sun for so long a time had their shadows in one position at the commencement of the experiment, and in another at the end. The result was a confusion of images, the tint becoming flat and uniform, and the relief eventually disappearing.

In any case, the original idea and the glory of inventing photography belong by right, in a great measure, to Niepce, though he had not the privilege of personally enjoying the triumph and sharing with his associate Daguerre the honour of national gratitude justly bestowed on the two inventors.[1] It was Daguerre who, by the invention of an original method, carried to perfection the new art of reproducing, by light, all the details of a view from nature, such as a landscape or a portrait.

[1] A law was passed in July, 1839, granting to Daguerre and Niepce's son two life pensions of 6,000 and 4,000 francs, on condition of their giving to the public the results of their inventions and discoveries in photography. Niepce, the father, died in 1833.

Many improvements were afterwards made in this process, which is now no longer practised, having been replaced by many others, more expeditious and less costly; but from the first the daguerreotype proofs attained a finish, a precision which have never since been surpassed. In a historical and scientific point of view, however, and as an application of the laws of physical phenomena, Daguerre's process has an importance which necessitates our describing it in detail. The enthusiasm with which it was received at the outset by savants and by the public, as well as by artists, was but its due, if we consider the immense services it has rendered, and which the new processes render still more. Geography, the physical and natural sciences, ethnology, architecture, and even the arts of drawing and painting, have been indebted to and have benefited from the aid of photography.

Let us see, then, what was the original process of Daguerre in 1839, and how he succeeded in reproducing pictures by means of the process which was then called the *daguerreotype.*

§ II.—THE DAGUERREOTYPE.

Daguerre employed, like Niepce, a sheet of copper of the thickness of strong cardboard plated with silver. He divided into five operations the series of manipulations which formed his process. The following description of them is taken from the notice published by the inventor.

The first operation consisted in cleaning and polishing the plate. The silver surface was first polished very carefully with some cotton steeped in olive oil and some very finely powdered pounce; the greasy coating was then taken off with a stopple moistened with nitric acid and water. The plate, made very hot, was again polished with pounce, this time dry, until the silver became perfectly bright.

In this state the plate was ready to receive the sensitizing bath, a second operation, which consisted in exposing the polished surface to the vapours spontaneously exhaled from some fragments of iodine.[1] This was done in darkness, and the operator could only judge by the

[1] It should be remarked that Niepce tried to bleach his bitumen with iodine, and after communicating this fact to Daguerre it is probable that this savant first observed the action of light on iodide of silver after repeating the experiment.

light of a candle whether the desired result was obtained; the silver coating should then have taken a beautiful golden hue. This operation required from three minutes to half an hour, according to the temperature.

The plate thus prepared was then placed at the focus of a lens in the camera, care being taken not to leave a longer interval than an hour between this third operation and the preceding one.[1] The objects to be copied were placed in the direct light of the sun. After this plate had been exposed for a certain time, varying with the time of day and with the season—and which for Paris was three minutes at least and thirty minutes at most—the photogenic action of the light was complete. The plate, on which nothing was yet visible, and from which the light had to be carefully excluded, bore a faithful impression of all the objects which had co-operated in sending to it luminous rays.

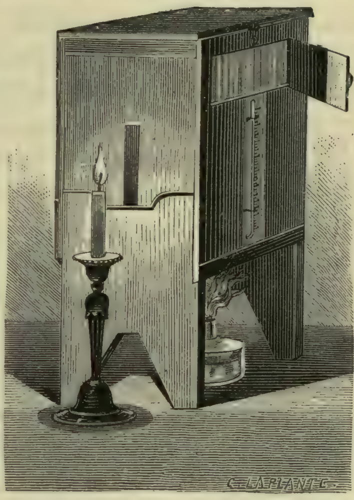

FIG. 217.—Mercury box for developing daguerreotypes.

It only remained then to develop this image, hidden as it were beneath a veil, and to fix it so as to preserve it from fading. Daguerre thus proceeded to effect these last two operations.

The plate was put inside a box, and the impressed surface, inclined at an angle of 45°, was submitted to the action of vapours, which escaped from a capsule containing mercury heated to a temperature of 60° to 75° centigrade. After some minutes the picture began to appear and to become more and more clear and accurate, a result which would be watched by the light of a candle. After the temperature of the mercury was lowered to about 45° the operation was complete, and the proof perfect. It could then be kept without changing for several months, if it were not exposed often to daylight. "The object of the fifth operation," says Daguerre, "is to clear the plate from the iodine,

[1] It was subsequently found that the sensitiveness of the plate was increased by allowing the iodized plate to remain half a day before exposure.

which would go on decomposing and destroy the proof if it remained too long exposed to the light." Was this interpretation scientifically exact? We shall see later on. The inventor always succeeded in his aim by shaking the plate in a hot solution of sea-salt, or better still, in a solution of hyposulphite of soda,[1] and then washing it in very hot water. When all trace of the golden coating had disappeared, this last operation was known to be successful. The proof was then covered with glass to save the surface from being scratched or rubbed, and it was thus preserved intact, even when exposed to the light.

This is an epitome of the method invented by Daguerre without the details of manipulation, which are devoid of interest from a scientific point of view. Improvements and processes were soon added which ere long dethroned the original invention, without in any way detracting from the merit of the two men who contributed to its discovery.

§ II.—Improvements made in Daguerre's Process.

We have shown with what enthusiasm the discovery of Niepce and Daguerre was everywhere received. As the manipulations required in this art were neither difficult nor expensive, and as, thanks to the law, the invention had become public property, a number of amateurs, artists, and scientific men set themselves to practise photography. The result was a series of modifications and improvements on the original method. We shall only mention the most important of these advances. From the outset attention had been directed to making the images as lasting as possible by protecting them from friction and from the ulterior action of light. M. Dumas proposed covering the plate with varnish, by pouring on the surface a boiling solution of one part of British gum in five parts of water. Mention must also be made of M. Fizeau's fixing with chloride of gold. After having carefully washed the plate in hyposulphite of soda, M. Fizeau poured over the whole surface a mixed solution of chloride of gold and hyposulphite of soda, then he heated the plate underneath with

[1] The solvent action of hyposulphite of soda had been discovered by Sir John Herschel in 1819. The introduction of this salt for fixing was long subsequent to the discovery of the daguerreotype.

a powerful lamp; gradually the image more grew distinct, and after one or two minutes came out very strongly. The thin coating of gold which covered the proof, by strengthening the tones, protected the picture from accidental changes. Daguerre's process required, as we have seen, a rather long exposure, on an average a quarter of an hour to the sun's rays. Attention was naturally directed to reducing this time, which on many accounts, limited the employment of the method. For portraits of living people and animals, or for moving objects, it was very important to solve this problem, which was in fact to discover compounds more rapidly impressible than iodide of silver. Several were found, and they were called *accelerating substances*, because they aided the action of the iodine.

In 1840 Goddard, and in 1841 Claudet, found that the iodized plate, exposed to the vapours of bromine, gained considerably in sensitiveness. After attaining a rose tint under the influence of these vapours the plate was again exposed to the vapour of iodine, until the surface had gained a violet tint. Among the accelerating substances since employed we may mention chloride of iodine, several preparations of bromide of iodine, of chloro-bromide of iodine, and several solutions known as *Hungarian liquid*, *German liquid*, some used without the aid of iodine, whilst others acted only in the wake of this chemical on the surface of the silver plate. Thanks to this increase of sensitiveness in the sensitizing substances, the processes in *heliography* (by this name Niepce from the first designated his method) were much more expeditious. Views and portraits were taken in a few seconds, and even the direct rays of the sun were dispensed with; diffused light sufficed for obtaining proofs, less vigorous certainly, but for that reason more harmonious and more artistic. The improvements made in cameras, and in optical apparatus, which will be described, have also contributed to this advance.

Before passing to the description of the photographic processes which were gradually substituted for those of the first inventors, let us return to the scientific physico-chemical interpretation of the phenomena we have been studying. We have nothing to say on the purely optical side of the phenomena; the formation of the images at the focus of the dark chamber has been completely explained in the chapters devoted to the phenomena of light and their laws, and to optical instruments, properly so called. But what takes place on the

surface of the plate? How are the images formed? What is the mode of action of the light, and how do the images, invisible at first, though formed, become visible in all their details?

We have already seen that the result of exposing the silvered plate to the vapours of iodine is the formation of a chemical compound, *iodide of silver*. It is this compound which covers the originally white surface of the metal with a tint which varies, according to the thickness, from straw colour, golden or orange, red and violet to blue. Let us remark, to begin with, that this phenomenon of colouring is not due to the colour of the iodide of silver, which is pale primrose, but to an action in which the interference of the rays of light plays the principal part, as we have seen in the chapter in the *Forces of Nature* dealing with the colours of thin plates. M. Dumas has measured the weight of the coating of iodine formed on the surface of a daguerreotype plate, and he has made an approximate estimate of the thickness of the coating itself. This summary is so curious that we will quote from the celebrated chemist's account:—"A plate of 5760 square millimetres in surface having been brought to a straw-coloured tint by exposure to iodine vapour, was placed on a very delicately adjusted balance, and the weight exactly ascertained; there was a decided increase of weight, but it did not amount to half a milligramme. When the shade deepened to golden, the weight increased to the half milligramme. By prolonging the duration of the action of the iodine vapour beyond the necessary time, by quadrupling it, for example, I obtained very appreciable effects in the balance: an increase of two milligrammes in weight. I supposed the quarter of this quantity would have sufficed to give the whole surface sufficient iodine to produce the image. But on calculating the weight of iodide of silver which this iodine represents, and the volume of iodide corresponding to this weight, the thickness of the coating of iodide of silver deposited on the surface of the plate is arrived at. It amounts to less than *the millionth part of a millimetre*."

When the metal plate, covered with iodide of silver and bromide of silver, has been submitted to the action of the accelerating substances, what happens when it is impressed by the light? What influence have the waves of light on the sensitive coating? On this point opinions differ. According to M. Dumas, whose opinion was circulated when Daguerre's discovery was made public, the action of

light is purely mechanical, its effects being to lift or split the coating of iodide of silver, and thus to allow the mercury to come in contact with the metallic silver, while the iodide that had not been split would remain impervious. On examining with a microscope the mercurial coating deposited after the third operation, the celebrated chemist found it to be composed of very irregular granules of mercury (their diameter averaging the 800th part of a millimetre). The white, or luminous parts, were covered with these granules; the shadows had scarcely any; whereas the half tints were less covered than the lights: in short the granules of mercury were deposited in quantities proportioned to the erosion of the iodide of silver.

Other *savants* think differently According to them the iodide of silver, under the action of the luminous waves, is partially decomposed; it is transformed into sub-iodide, which, in contact with proto-iodide of mercury, gives us red iodide and metallic mercury. According to this theory, which was propounded in 1843 by Messrs. Choiselat and Ratel, "the lights are produced by a very thin dust of amalgam of silver simply deposited on the plate; these lights are brilliant in proportion to the amount of silver in this dust; the shadows are the result of a very scattered deposit of silver, mechanically mixed with a diluted wash of mercury."

Whichever may be the true theory, whether the granules are formed of amalgam or of metallic mercury, this deposit on the surface of the plate forms a very unstable compound, and, in either case, there is the same necessity for protecting it from external disturbance. Hence the importance of the gilding operation, which was obtained for daguerreotype proofs, as we have seen, by the deposit of a thin transparent coating of hyposulphite of gold.

CHAPTER VII.

PHOTOGRAPHY ON PAPER AND ON GLASS.

§ I.—PHOTOGRAPHY ON PAPER.—TALBOT'S INVENTION.—BLANCQUARD-EVRARD PROCESSES.

As the names of Niepce and Daguerre are associated with the first invention of photography on metal plates, so those of Talbot and of Blancquard-Evrard characterize the discovery of photography on paper: Niepce and Talbot[1] having the glory of conceiving the idea; Daguerre and Blancquard-Evrard of having practically realized and perfected the process of the original inventor.

Less than two years had elapsed since François Arago and Gay-Lussac had made their reports in the Chamber of Deputies and in the Chamber of Peers on the invention of the daguerreotype, when a letter from an English scientific man, Fox-Talbot, read at the Academy of Sciences by Biot, explained the processes he had discovered for reproducing images directly on sensitized paper. According to this communication Talbot's process is as follows:—

"With a solution of nitrate of silver in pure water wash one of the sides of a sheet of paper, previously marked to recognize it, and then dry gradually. After this plunge it for two minutes into a solution of iodide of potassium. By mixing a solution of nitrate of silver with a solution of gallic acid and a small quantity of acetic acid, gallonitrate of silver is formed, in which the iodized paper must be washed. The paper thus saturated is then plunged in water and dried with blotting paper, and

[1] Niepce and Talbot, in June 1839, six months previous to the publication of the daguerreotype process, read a paper before the Royal Society, giving an account of a process of photographic printing which is similar in its main outline to that practised at the present time.

we have thus obtained *calotype* paper. It is placed at the focus of the camera, one minute suffices to imprint the image, which appears with all its details, when, after having washed the paper in the gallonitrate of silver, we warm it gently before the fire. To fix the picture it must be moistened with a solution of bromide of potassium, and again washed and dried. Drawings fixed in this way remain transparent, and they may be copied on another sheet of *calotype* paper, which is pressed against the picture and thus exposed to the light."

In this process we find the same physical principles as in those of Niepce and Daguerre. A sheet of paper is covered with a sensitized coating impressible to the light; it is submitted to this influence at the focus of a camera. Still invisible when removed from the camera, the image requires the action of a special substance, of an operation which will *develop*[1] it; finally, to preserve it from causes of ulterior destruction, a last operation is necessary, that of *fixing*.

All the subsequent photographic processes, and they are numberless, are based on the same principles and necessitate the same fundamental operations.

In what particulars, then, did Talbot, who at first furnished proofs in many points defective, show an advance in the new art? In this. Daguerre's plates were heavy and expensive, embarrassing when traveling, and awkward in manipulation. Besides, the image, notwithstanding its admirable accuracy and the finish of its details, has a dazzling reflection, which makes it difficult to examine; one can only see it under certain conditions of light. Moreover, one proof is the only result of the operation, which must be recommenced as often as fresh copies of the same object are required. On all these points, but especially on the latter, that of reproducing copies from the same proof, the process of Talbot showed a considerable progress, and this progress was practically realized in a few years.

First, M. Blancquard-Evrard, of Lille, succeeded, by improving on Talbot's process, in obtaining more and more perfect proofs on paper, and while improving the results, he found means of succeeding almost without failure, a thing which could not be said for the process described above. Let us succinctly describe his method.

[1] The development of images by gallic acid and nitrate of silver was the discovery of the Rev. J. B. Reade, from whom we may suppose Fox-Talbot borrowed it for the autotype process.

Like Talbot's process, this method embraces two principal operations: first, by the aid of the camera, a *negative* proof of the image is obtained, that is to say, an inverse image; the lights being represented by *shadows,* the shadows by *lights,* and all the half tints by mixtures in the exact proportion of the extreme tints. By help of this negative are taken *positive* proofs, in which the image resumes its normal appearance; and these proofs can be afterwards obtained in an indefinite number.

The negative is obtained on sensitized paper, and it was chiefly in the preparation of this paper that M. Blancquard-Evrard made improvements. Instead of only covering the surface with the sensitized coating, he impregnated the whole thickness with iodide of silver; placing the still moist sheet between two glasses, he exposed it at the focus of the lens. The paper was obtained in the following manner:—

Some very compact, thin, even and well-made paper was chosen, and placed with one of its surfaces on a solution of nitrate of silver, taking care that the other surface should not be moistened with the liquid, and that the contact should be complete without the interposition of air bubbles. After some minutes the sheet was stretched on a glass, the damp side uppermost, and left to dry in the dark. The dry paper was then immersed in a solution of iodide and bromide of potassium, when, a double chemical decomposition taking place, two impressible substances, iodide of silver and bromide of silver, were simultaneously formed, and penetrated the whole thickness of the paper.

By employing the photogenic paper whilst still moist the image is impressed rapidly (an indispensable requisite in reproducing animate objects, especially portraits). The dry paper requires a longer exposure to the light: it is useful when travelling, for securing views, landscapes, monuments, and so forth.

The paper when taken from the camera showed a blank surface like the daguerreotype plates. But here the developer is a solution of gallic or pyrogallic acid, in which the sheet of paper is plunged. This organic acid reduces the iodide of silver wherever the light has made an impression, and the parts thus impressed are covered with a dark tint of metalic silver, distinct in proportion to the action of the light. The proof is therefore negative. To render it unchange-

able under the action of light, it is washed in a solution of hyposulphite of soda, or in a bath of bromide of potassium; the iodide of silver which has not been decomposed is thus carried off, and the image is fixed.

By help of the negative image thus obtained a positive proof can now be produced, by a process analogous to that originally used by, Niepce in copying engravings. The negative proof is soaked in wax, so as to render the paper translucid, or even transparent. This proof is then placed on a sheet of sensitized paper, and the two sheets, between two glasses, are then exposed either to the direct rays of the sun or to the diffused light of day. Under the influence of the light the sheet of sensitized paper is impressed with a positive image, invisible at first, but developable by gallic acid as before.

§ II.—Photography on Albuminized Glass.

Photography on paper became rapidly popular, and if the proofs lacked much of the delicacy of the daguerreotype plates, and if minute detail was absent on account of the grain and of the fibrous texture of paper, the new pictures were, on the other hand, more appreciated by artists. Moreover, in this second phase of the art, improvements cropped up with astonishing rapidity.

Proofs were made on waxed or gummed paper with a surface so highly polished that the most delicate details could be reproduced. But soon a new discovery, made by a nephew of Niepce, M. Niepce de Saint-Victor, opened up a new path for photography, which is still the one most generally followed. Instead of taking a metal plate, like Daguerre, or a sheet of paper, like Talbot and Blancquard-Evrard, for the deposit of the sensitized coating, M. Niepce de Saint-Victor succeeded in depositing the sensitive compound on a highly polished plate of glass, and producing on it a negative proof. The transparency of the glass, its durability, the polish of its surface, its cheapness, all these advantages have by degrees induced photographers to substitute it for the metallic plates of Daguerre, and for the sensitized paper. Before arriving at the process most generally adopted at the present day, which is photography on collodion, we will describe the process of M. Niepce de St.-Victor:—The sensitized coating with which he

covered the glass plate was formed of a liquid composed in the following manner: albumen, obtained by beating white of egg to the consistency of snow; iodide of potassium, 1 per cent.; water, 25 per cent. The glass, covered with a very even coating, is put to dry in the dark, and this requires nearly a whole day. It is then immersed in a solution of aceto-nitrate of silver, and a plate is ready prepared to the action of the light. From fifteen to thirty seconds are a sufficient exposure.

The negative proof being thus obtained, we take positive proofs from it, as described above. These proofs being on paper, we again have the inconvenience of the grain, but with this considerable difference, that, the positive proof alone being taken on it, the delicacy of contours, features, and shades is less damaged, the negative picture being perfect in all its details. Again, nothing prevents our avoiding this inconvenience, by taking the positive proofs on albuminized glass. This is done more particularly for stereoscopic pictures, transparency being essential in using the stereoscope with transmitted light.

§ III.—PHOTOGRAPHY ON COLLODION.

Schoenbein discovered in 1846 a substance which attracted a large share of scientific and public attention. It was thought for a time that this substance, known as gun-cotton, or pyroxyline, would entirely replace ordinary gunpowder. Pyroxyline is prepared in a very simple manner, by steeping carded cotton in nitro-sulphuric acid, washing it in water and drying it in the air. It is soluble in a mixture of alcohol and ether.

This solution, which is used in surgery and medicine, is named collodion. An English photographer, Mr. Archer, suggested, in 1851, the substituting of collodion for albumen in preparing the glass plates for the negative proofs. Albumen and collodion play the same parts; but the pictures made by the latter process require even less exposure, and the effect may be produced almost instantaneously. Hence the possibility of reproducing views containing animate objects, of seizing the rapidly-varying expressions of physiognomy in portraits, of representing bodies in motion—clouds scudding before the wind, the waves in a rough sea, and the like. The processes in

collodion photography have been varied in a hundred ways: in describing what is required in one of these we shall have elucidated all the others. But we must repeat that here, as in the daguerreotype, as in photography on paper and on albuminized glass, we omit all details of the manipulation, although they are of the highest importance, for they are frequently indispensable conditions of success. As it is not our intention to make this even an abridged manual of photography, but to make the physical principles of this widely-practised art clear, we merely give the formula of normal collodion as prepared before the addition of those substances which contribute to the production of the sensitized coating, and which is as follows:—

Rectified sulphuric ether	600
Pyroxyline	12
Alcohol at 40°	300

The iodized liquid is an alcoholic solution of the iodides of potassium, cadmium, and ammonium, and of the bromides of the same metals. To this is added a fragment of iodine. The liquid formed of the mixture of these two solutions is, like the albumen, allowed to coat a well-cleaned glass. Just before the coating is dry, the glass is plunged in a bath of nitrate of silver. The formation of iodide and bromide of silver which ensues produces a whitish, opaque film, which is sensitive to light; hence this operation is always performed in a room which is glazed with yellow or red glass, the blue and violet rays being those which are generally photographically active. The glass is then placed in the slide of the camera, and it can now be operated on—that is, exposed to the action of the light. In a few seconds, the impression is produced, and it only remains to submit the proof to the operations of developing and fixing the image. The former is accomplished by an acid solution of protosulphate of iron or pyrogallic acid, and the latter with hyposulphite of soda or cyanide of potassium.

If a collodionized plate prepared as above be washed and be then coated with albumen, it may be dried and exposed in the camera even months after preparation. This is Taupenot's process with dry collodion.

Having obtained the negative proof, we proceed, as before described, for the positive proofs.

§ IV.—The Optical Apparatus employed in Photography.

Now that we have given an idea of the principal methods of photograhpy which have succeeded each other since the invention of Niepce and Daguerre, it will be well to revert to a point common to all, and to enter into some details on the optical apparatus—namely, on the arrangement of the camera obscura with its most important accessories.

The camera obscura, ordinarily called a camera, is in its simplest form composed of a rectangular wooden box, formed of two or more compartments resting on a sliding board. This enables the box to

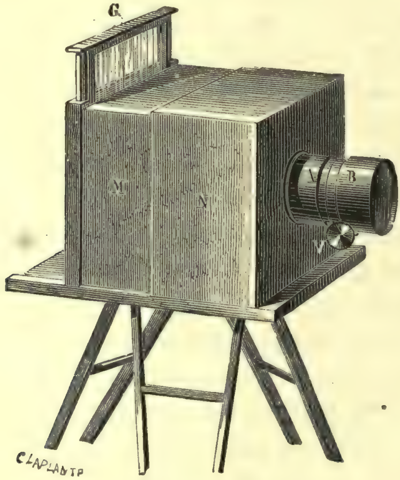

Fig. 218.—Photographic camera.

be lengthened or diminished at will in one direction. Cameras are now frequently made on the principle of bellows, avoiding the necessity of the different compartments of the box.

In front is an opening, AB, carrying a tube, holding the object-glass. In this are arranged the glasses or lenses destined to produce the image of the objects to be photographed. The back of the camera is arranged to receive in a groove the frame G, which holds the sensitive plate on which the light is to impress the image. Before admitting the light, however, to the sensitized surface, it must be ascertained that the image is well in focus. This the operator

effects by first placing in the frame a ground glass, on the surface of which the image can be seen. If this image be not clear, the ground surface of the glass is not in focus; and the defect must be corrected by moving the sliding sides of the camera, either lengthening or diminishing the distance till the exact focus is found; this is called "focussing the image," a similar operation to that which we have described for the lenses of telescopes and microscopes.

The clearness of the image depends on the quality of the object-glass, which should be achromatic, and without spherical aberration.

Figs. 220 and 221 give sections of two different forms of object-glasses, some simple, others compound. The simple object-glass often requires a diaphragm in front of it having a small opening.

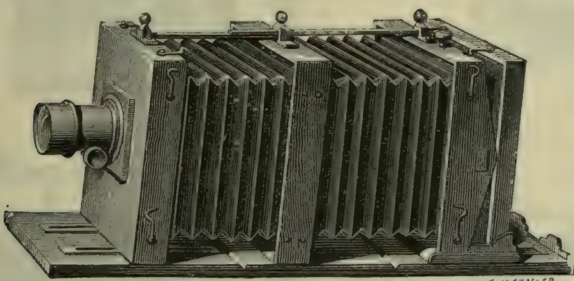

FIG. 219.—Country photographic apparatus, bellows shape.

The quantity of light passing through a narrow opening being limited, this object-glass sometimes requires a prolonged exposure. It is used more especially for views, landscapes, &c.

The object-glass with a combination of lenses (Fig. 221), and with the diaphragm placed between them, permits the entrance of a larger quantity of light; it is employed, in preference, for portraits, because the exposure required is not so long.

In daguerreotypes the image was reversed on the plate, so that the right side appeared at the left, and *vice versâ*. To obtain a direct image, either a total reflection prism, or a mirror inclined at 45°, was adjusted to the object-glass. This precaution is not required in photography on glass, because it is the negative proof which is inverted and symmetrical, and by turning it to obtain the positive proof, the latter is found to be in the normal position.

In the first years which followed Daguerre's discovery, the ablest operators, in spite of the most careful manipulation, frequently failed, and seldom obtained proofs possessing the clearness of the image as seen on the unpolished glass. At first, this was supposed to result from the difficulty in making the surface of the plate coincide accurately with the unpolished surface of the glass. A photographer, M. Claudet, sought to remedy this inconvenience, and he succeeded. But the result was contrary to his expectation. The proofs obtained were still confused and ill-defined. After fresh researches, he discovered the cause of non-success: it was, that the focus of the visible

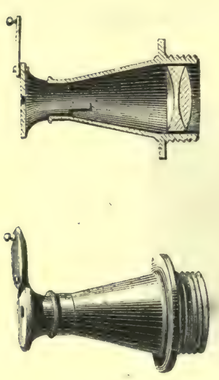

FIG. 220.—Simple object-glass.

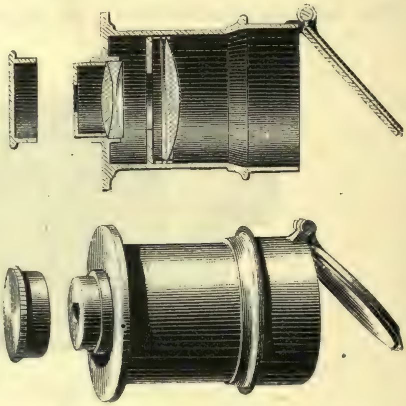

FIG. 221.—Complex object-glass with adjusting-lens.

rays of light does not coincide with that of the chemical rays—the photogenic focus. And this difference depends on the nature of the glass employed, the distance of objects, and the intensity of the light. The problem has since been practically solved by opticians, who construct object-glasses in which the photogenic and visual focuses coincide. When the object-glass of an apparatus has not this property, it is important that the photographer should study it with care, and, by multiplied attempts, succeed in finding the exact position of the frame in which the image on the rough glass will be found to coincide with the chemical focus, so as to produce the most accurate image possible on the sensitized glass.

We have said nearly all that is necessary, in a scientific point of view, on this interesting application of physics and chemistry to the

art of drawing. We have still, however, to mention a series of discoveries, recently made in the domain of photography, which have an interest for physicists and artists.

§ V.—Photography with Artificial Light.

Heliography, as we have seen, is founded on the property of the rays of light to affect chemically those substances said to be impressible or sensitive; it is the chemical radiation of the sun either directly or in the light of day—that is, diffused solar light—which has these photogenic properties. But the question was soon raised and soon settled by physicists and photographers, whether the sun's light could not be replaced at need by other light more or less intense.

The electric light, from its powerful intensity, claimed the first attention. Its colouring power on chloride of silver had long been known, having been demonstrated by Brande soon after the discovery of the voltaic arc by Davy. M. de la Rive stated later that it acted on daguerreotype plates, and this savant obtained the image of a plaster bust, illuminated by the dazzling light of electricity. The application of this source of light to photography is now practically in use, as we find by the following notice, which we quote from *Les Mondes* of October, 1866:—"Mr. Woodbury, of Manchester, continues to employ, in the production of photographic negatives on gelatine, the electric light produced by Wilde's machine. This light, produced between the points of two pieces of carbon, is surrounded by negatives which it must penetrate to impress the gelatine; and we maintain that the reliefs on gelatine obtained with the electric light are better defined than when obtained with sunlight or daylight." This notice evidently relates to a process of heliographic engraving which we shall mention later; but what follows relates to the production of real photographic negatives: "Messrs. Saxon and Co., also of Manchester, use now, exclusively, Wilde's electric light in enlarging photographs. In possession of an artificial light which shines day and night, they are enabled to undertake to enlarge, in twenty-four hours, the negatives entrusted to them."

This light is however very costly. In the rare cases when photography at night is necessary, a preference is given to the light

produced by the combustion of magnesium. The invention of magnesian lamps by Sir David Brewster and the improvements which were made in them by M. Le Roux, in mixing zinc with the magnesium, have facilitated the application of this artificial light to photography. Engravings, busts, and statues were first attempted, and thus was recognized the photogenic value of the magnesian light, which moreover is less costly than the electric light.

By this method, inanimate objects may be advantageously reproduced; but, in an artistic point of view, the effect is unsatisfactory on account of the necessarily exaggerated contrast of light and shade. The photographic portraits by magnesium have a cadaverous appearance. On the other hand, we have obtained images of objects which would otherwise have escaped the photographer's art; for example, the interior of one of the pyramids of Egypt, and of the celebrated caverns of Kentucky, known as the Mammoth Caves; the magnificent stalactites of those subterranean rocks have thus been reproduced with the utmost fidelity. Subterranean curiosities, like the catacombs of Rome, and those of Paris, have also benefited by this mode of illumination.

Other artificial lights have been tested, with more or less success, for the production of photographic images. Such are the lights produced by the combustion of a jet of oxyhydrogen gas, projected on to solid fragments of refractory matter: lime, magnesia, zirconium, chromium. Van Monckoven has obtained enlarged proofs on collodion or on paper, in a space of time varying from one to three minutes, by the light of the gas blow-pipe projected on a mixture of titanic acid, magnesia and carbonate of magnesia. It is not, after all, so much the luminous intensity of the source which is favourable to the reproduction, as the quantity of chemical rays emitted.

§ VI.—Enlarged Proofs.—Microscopic Photography.

It is evident that by projecting, with the aid of a solar microscope, the image of a photographic proof on a sensitized surface, an image will there be formed with all the details of the original enlarged. It this be done with a negative, the result will be a positive; but an enlarged negative may also be obtained, and as many positives as are required may be obtained by the ordinary means. This last process is much more expeditious, and is as follows:—

First we obtain, from the negative a positive of the same size. This we submit to the amplification of the solar microscope, so that the enlarged proof is a negative. This proof is obtained on a collodionized glass, which has been sensitized by the usual processes. When exposed and fixed, the negative proof, enlarged to the required size, supplies positives. In this way the enlarging optical apparatus is only used once, and the rapidity of this method is very great.

The difficulty in the enlargement of photographic proofs consists in rapidly obtaining very clear proofs undistorted and preserving the vigour of tone of the proofs obtained in the first instance. At first, enlarged photographs were very unsatisfactory in these respects; but, by perseverance, they have been brought to wonderful perfection. At the Universal Exhibition of 1867 might be seen a magnificent full-length portrait, and an enlarged view of Amiens Cathedral, which, composed only of four pieces, measured no less than two metres in width and two and a half in height. Applied to astronomy, we shall see that this method of enlarging, in the hands of able and scientific operators, has produced remarkable results.

The importance of this process—not so much for ordinary views and portraits, as for the reproduction of objects whose multiplied details escape the pencil of the most patient and talented artist—will be understood. The wish of Arago, with regard to Daguerre's invention, that faithful reproductions might be obtained of the thousands of hieroglyphics covering the monuments of ancient Egypt, is realized at the present day, thanks to the enlarging process in photography!

If the image, some centimetres in diameter, of a body like the moon, may thus be transformed into a proof of a metre or more in diameter, enabling us to study at leisure the orthographic configuration of our satellite, how much more precious is the enlarging method for fixing the thousands of images of those natural objects which, by their minuteness, escape the eye! To obtain this result, the clearest possible images of these infinitesimal atoms had to be produced. This object has been realized, and the result is an entirely new branch of the art,—*microscopic photography.*

This new step is due, in a great measure, to M. Bersch; who has invented the optical instruments necessary for the production of microscopic images, for their subsequent amplification, and the arrangements necessary for the different operations required in their

production. Others have contributed to improve these processes and to obtain proofs of great perfection; we may mention, among others, M. Neyt (of Brussels), Messrs. Dagron, Moitessier, Lackerbauer, Girard, in France. Every one knows those marvellous and imperceptible photographs, portraits, views, monuments, &c., the size of a pin's head, which, framed in the collet of a ring, or in any ornament, can be seen with a magnifying-glass in their natural dimensions. Adapted to the kind of magnifier already described (page 235) as the *Stanhope Magnifier*, these little objects carry with them the microscope which enables them to be seen enlarged in every detail. A spot, hardly perceptible to the naked eye, becomes a whole page of a book which may be read as easily as the original. This charming invention we owe to M. Dagron.

This is, however, a mere object of curiosity and fancy; but microscopic photography is not restricted to these miniatures of a doubtful interest. It is applied to useful reproductions, and it has found a wide scope in zoological and vegetable micrography.

In presenting to the Academy of Sciences microscopic proofs of diatoms obtained with different magnifying powers, M. Girard thus expressed himself on the means he employed—means, identical with those of ordinary photography, with the sole difference, that the reproducing object-glass is replaced by a much smaller one, illuminated by solar light reflected by means of a plane or concave mirror, according to circumstances. A glass of a bluish shade is interposed to absorb a portion of the non-actinic light. When it fails in intensity, as when deep object-glasses are used whose front lens is hardly a millimétre in diameter, it is necessary to have recourse to a condenser.

"Photomicography," says M. Girard, "is a perfectly exact means of resolving the most difficult *tests*; the image obtained proves, in a manner not to be refuted, the value of the optic system of the microscope. It enables us, further, to catch distinct effects of light, otherwise unattainable; interference and diffraction often give rise to remarkable combinations."[1]

The same author has made another application of microscopic photography by studying, with the aid of polarized light, the crystals of certain salts.

[1] *Comptes Rendus* (1869).

In medicine, in physiology, this branch of photographic art has rendered valuable services. Dr. Ozanam has designed an apparatus which registers, photographically, the beats of the pulse in every phase; he obtains thus an undulating line, which, when magnified, shows all the variations which are produced in the pulsation during the short interval of the hundred-thousandth part of a second.

To sum up, the innumerable forms discovered by the microscope in the domain of natural science, are permanently placed before us by photomicography, and, by enlarging the proofs, we are enabled to study them at leisure and with ease.

During the siege of Paris, this application of photography rendered service of a different kind. It enabled the longest and most voluminous despatches to be reduced to a surface of a few square centimetres, and to be conveyed under the wings of carrier-pigeons from the provinces to Paris. The organization of this microscopic post was commenced at Tours under the direction of a photographer of that town, a M. Blaize. The reduced proofs were first made on paper; two pages of print were condensed on each side of the sheet; but the grain in the paper limited the fineness of the text, and besides, the time for exposing it (in winter) was considerable. Hence the system which M. Dagron, who was sent from Paris to Tours by balloon, proposed to the Delegation, was preferred (end of November 1870). This photographer operated on thin pellicles of collodion, very light and sufficiently sensitive to need only two seconds exposure instead of two hours. He thus describes his method :—

FIG. 222.—Microscopic photograph. Facsimile of a despatch sent to Paris during the siege.

"Each pellicle was the reproduction of twelve to sixteen pages in folio of print, containing on an average, according to the type, three thousand despatches weighing together *less than half a gramme.* The whole series of official and private despatches made during the siege of Paris, numbering about one hundred and fifteen thousand, weighed *one gramme.* One single pigeon could have easily carried them. If one multiplies the number of despatches by the number of copies

furnished, the result will be more than two million five hundred thousand despatches produced during the two worst months of the year.

"The pellicles were rolled into a quill which was tied by agents of the administration to the pigeon's tail. Their extreme suppleness and complete imperviousness adapted them for this service. My dry preparation has, besides the triple advantage: of being got ready in one operation, of having a uniform surface, and of not separating from the glass on the appearance of the image; it is worked with perfect security and it is not exposed to the mischances of the ordinary processes."

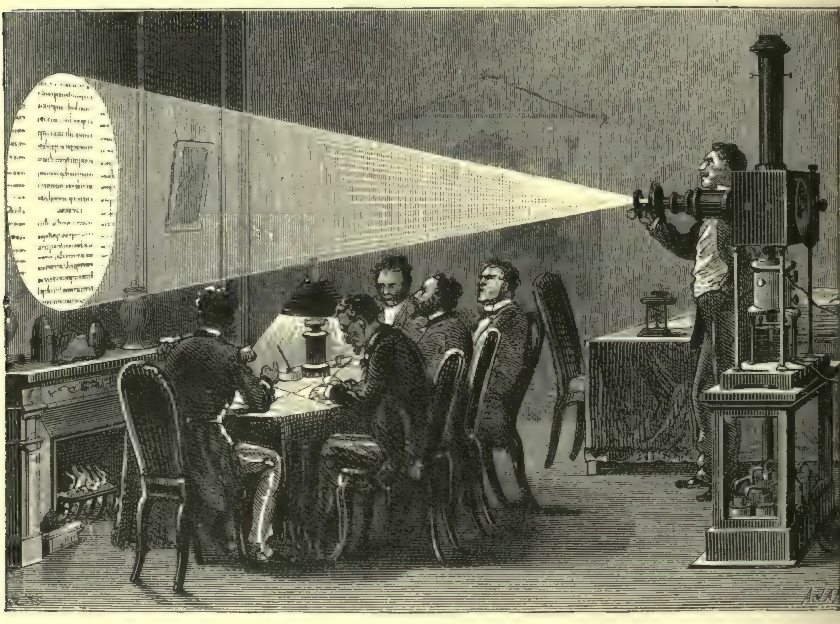

FIG. 223.—Enlarging and reading the microscopic despatches during the siege of Paris.

When the microscopic despatches had reached Paris, they were submitted to the operation of enlarging, and projected, by a solar microscope, illuminated by the electric light, on a white board. There a copy could be taken of their contents. The transparency of the collodion films facilitated this projection, and the text was read with ease. This was assuredly one of the most useful and ingenious services which physical science and the art of photography could furnish, though unfortunately too late, towards the national defence.

CHAPTER VIII.

HELIOGRAPHY—PHOTOLITHOGRAPHY.

§ I.—DIFFERENT PERMANENT PROCESSES WITH CARBON AND PRINTING INK.

WHATEVER process may be employed for fixing daguerreotype or photographic proofs, it is certain that they do not possess the permanency given by the ordinary impression made with almost indestructible printing inks. Any photograph can be reproduced almost indefinitely by printing, and thus increasing the chance of preserving the image obtained; but each positive proof may be deteriorated in the long run, and its clearness impaired under the prolonged influence of light; and finally, supposing this problem of permanency be solved, there would still be, in the printing of positives, vast differences between the typographic and lithographic printing of engravings, both as regards cost and time.

It is not to be wondered at then that, from the first, this difference has been fought against, by endeavouring to transform the photographic proof into a real engraving block in relief or copper plate, or lithography. This was the problem pursued by Niepce, from his earliest labours, and which numbers of artists and men of science have since tried to solve. We will glance at the principal methods adopted, and the results at which they have arrived.

About 1841, M. Fizeau tried to reproduce the images on Daguerre's plates by electroplating: the copper deposited by the galvanic pile moulded itself on the surface and represented the reliefs inversely, that is to say all the points to which the mercury had spread formed the lights. By using this mould to obtain an inverted proof, the plate itself was reproduced, and it only remained to print it by the

ordinary processes. Unfortunately, the reliefs were so slightly pronounced that the images reproduced were very confused.

Messrs. Berres and Donné then tried to obtain blocks by attacking the daguerreotype plates with *aqua fortis.* Mr. Grove combined the two foregoing methods by subjecting the plate to one of the elements of a voltaic combination which acts unequally on the two metals, silver and mercury.

M. Fizeau at length designed a process which transformed daguerreotype plates into copper-plate engravings. He operated quickly on the image with a mixed acid composed of nitric, nitrous, and hydrochloric acids: the light spaces remained intact; the dark were affected, and an adhesive chloride of silver was formed, which arrested the action of the acid. This coating was dissolved by a solution of ammonia, and the action of the acid continued. To obtain more depth, M. Fizeau gilded the raised parts, which were thus protected from subsequent action of the nitric acid. Silver not being a hard metal, and consequently only bearing a limited amount of printing, the block was coppered by galvanic processes (now, copper-plate blocks are faced with steel).

These were certainly remarkable experiments; but, as the primitive process of Daguerre was soon replaced by photography on paper and on collodionized or albuminized glass, the attempts at engraving daguerreotype plates were abandoned.

Towards 1853, M. Niepce de Saint Victor obtained engravings on steel in the following manner: he covered the engraving block with the coating of an impressible varnish formed of bitumen, benzine, wax and sulphuric ether with a few drops of oil of lavender. To the plate when dry he applied a positive on paper or glass, and exposed both to the light, as in obtaining a proof. When the impressed plate had passed through oil of naphtha mixed with benzine it was submitted to a mixture of nitric acid and alcohol. The engraving was finished off with *aqua fortis.*

Among the numerous processes since invented for printing off photographic proofs with printing inks, we must cite the process invented by M. Poitevin, called the *carbon* process. We shall only briefly indicate the principle of it, and we shall dwell on the results alone, because this process is a part of the photographic art, not, properly speaking an application of physics: it is rather an application of chemistry.

M. Poitevin describes his process in the following terms:

"To reproduce by printing ink the counter proof of a photographic drawing, on paper, lithographic stone, metallic substance or wood, we apply to the surface intended for the reception of the drawing, one or more coatings of a mixture in equal parts of a concentrated solution of albumen, fibrine, and gum arabic, and a concentrated solution of a chromate or bichromate with an earthy or metallic alkaline base not precipitating the organic matter of its solution. Generally the bichromate of potassium is used; after desiccation or before, if the impression has to be made in the camera, it is exposed to the light, and after the insulation, a uniform coating of printing or coloured ink is applied with a stopple or by a press; the ink is washed off: the ink only remains on the parts impressed by the light."

To obtain reliefs or depressions by the action of light alone, without employing the corrosion of acids, or the tool of the graver, in a word to produce blocks engraved by light alone, the inventor proceeds as follows:—He spreads on whatever surface he is using a uniform coating of a solution of gelatine impregnated with bichromate of potash. After desiccation, a positive or negative proof obtained by photography is placed on the coating and they are submitted to direct or diffused sun-light. The same plate can be exposed in the camera,[1] if a view from nature is to be taken: after exposure the gelatine coating is immersed in water; when all those parts which have not received the luminous impression absorb this fluid, the gelatine swells and gives the reliefs, while the unimpressed parts which become very slightly moist, form the hollows. The reliefs correspond to the shadows of the drawing, and the hollows to the lights.

By these means a block engraved on gelatine is obtained, which is afterwards transformed into a block on copper by the ordinary processes of electro-plating.

The carbon process with printing inks only justifies its name by the printing off the proofs by the means of impression with printing ink. The permanence of the proofs is due to the use of this ink, into which

[1] The exposure required renders this method of obtaining a photograph practically useless.

carbon (lamp black) enters as an ingredient. But, in reality, the whole

FIG. 224.—Facsimile of a heliographic engraving.

process is based on the properties possessed by some organic substances

(albumen, gum, gelatine) impregnated with alkaline bichromates, of being acted on by light and becoming insoluble.

M. Poitevin's invention was not so successful as he expected: only the strongest parts of the image came out well, the half tints were carried away, because, as M. Laborde discovered, the impressed coating was very thin and the gelatine coating underneath dissolved in water and carried away with it the lightest parts of the image. A French photographer, M. Fargier, found a means to remedy this inconvenience by developing the proof on the side of the gelatine opposite to the impressed surface. The Poitevin process has been much improved both by himself and by other inventors and operators, and M. Poitevin has applied it to lithography, and to typographic or copper-plate reproductions. To obtain a photographic image on stone, he operates as follows:—

Some albumen or bichromate of potash is deposited on the grained stone, which receives, when dry, a negative photographic proof; it is then exposed to the light. The stone is found to be acted on, so that the ink only adheres to the impressed parts, that is to those which correspond to the shades and half tints of the image. The printing off is continued, as for ordinary lithographic impressions.

It will be apparent that it is the gelatine that receives the ink and not the stone, and hence not many prints can be pulled off the stone. To Sir Henry James, R.E., and Major de Courcy Scott, of the Ordnance Survey, we are indebted for the first published method of practical photolithography, though about the same time Osborne in Australia brought out a somewhat similar process. Sir Henry James's plan was to coat paper with gelatine, cover it with greasy ink, after exposure beneath a negative of a zinc engraving or map, and float the back of the paper on hot water. This caused the gelatine to dissolve and to carry away with it the ink from those spaces which ought to be white. After sponging carefully with a fine sponge to aid the operation, a perfect *facsimile* of the original was presented to the eye. This was then placed face down on a lithographic stone or on a zinc plate, and after pressure in the lithographic press, the greasy ink left the paper and adhered to the one or the other. Several other modifications have been made of this method, but another, which is due to Captain Abney, F.R.S., is perhaps an improvement. In his process a positive picture is secured on gelatinized paper, the gelatine of which has

been hardened by the addition of chrome alum, and it is immediately placed in cold water. The gelatine absorbs water where the light has not acted, but refuses it in the other parts. When a roller charged with greasy ink is passed over the surface the ink adheres to the dry portions and leaves the moist parts intact. A perfect *facsimile* is thus obtained with a minimum amount of labour. A good transfer can be obtained five minutes after the positive print in gelatine leaves the printing-frame. The picture is transferred to stone or zinc in the ordinary manner.

Several processes for obtaining printing-blocks to be set up with type are extant. One of the most successful is that of Gillot. He transfers a true picture of an engraving in greasy ink to zinc and eats away the metal by acids, thus leaving the lines in relief. Another process which has been worked out by Captain Abney is dependent on the electrical action set up between two metals when one is deposited on the other in a fine state of division. He obtains a proof on a metal plate in resin which has become sensitive to light by a preparation of bichromate of potash, and which becomes insoluble in acids where the light has acted. He then covers the plate with a weak solution of nickel, platinum, silver, &c., from which these metals are deposited in a fine state of division. It is then placed in a solution of chlorine, hydrochloric acid, or other solvent, and the lines are left in relief. The use of the deposited metal consists in allowing a solvent of such a weak character to be employed that ordinarily it would not attack the plate; hence there is no undermining of the lines. Warnerke's method appears to be similar.

§ II. Relief Impression.—Woodbury Process.

A curious process of heliography, derived from M. Poitevin's, has been invented by Mr. Woodbury, who calls it *relief impression.* After having obtained on a thin film of collodion, covered with bichromated gelatine, the reliefs and hollows arising from the unequal swelling in water of the gelatine under the influence of the light, the plate is dried with a gentle heat. The swollen parts in relief are the shadows of the image. This done, Mr. Woodbury submits the plate in relief covered with a plate of metal (a mixture of type metal and

lead) to the action of a hydraulic press. The reliefs of the gelatine sink into the metal.

The metallic impression thus obtained is used in a printing process which is absolutely original. It consists in pouring an inky fluid (gelatine coloured with carbon, or otherwise) on the levelled metal plate and superposing a sheet of resinized paper and submitting it to pressure in a heavy press. What is the result? The sheet of paper, pressed by a plate of glass, drives the excess of ink to the edges of the mould, and the hollows alone remain filled. As soon as the gelatine is set, the paper, taken out of the press, carries with it the coloured gelatinous coating. The latter then forms on the paper a drawing in relief, which, however, diminishes as the gelatine dries. Wherever the gelatine is thickest, the tint is strongest, shading off to white where there is no relief.

It is impossible to give in detail an idea of the numerous processes of heliographic printing. They are all based on the fact that chromated gelatine when exposed to light becomes non-absorbent of water in exact proportion to the intensity with which, and length of time for which, the luminous rays act. If a gelatine film, supported on glass *per se*, be exposed under a negative possessing lights and shades it will absorb water according to the density of different parts of the negative. When a soft lithographic roller coated with greasy ink is passed over it while moist, the ink will adhere in proportion to the non-absorption of the water. A piece of paper placed over such an inked-in surface and pressed into it in a printing or lithographic press will take away an impression, giving the lights and shades in proper gradation.

It is only fair to mention the names of some of the inventors—Baldus, Nigré, Placet, Albert of Munich, Edwards, Du Gardin, Tessié du Motay, Waterhouse, Jeanrenaud and Thièl.

The results are certainly remarkable, but many of the processes are defective in one particular, viz., the difficulty of printing off a great number of impressions from the same surface. While this difficulty remains heliography will be incomplete; it will be unable to respond to the wants of artistic industry, and of the trade, which require a low price, and which is impossible while the printing-off remains circumscribed. With some more modern processes, such as those of Edwards and Thièl, the defect does not exist, it being possible

to strike off several thousand copies. The only objection to be overcome is that of being able to pull off the impressions by machinery, and independently of the skill of workmen. When this is the case, these processes will be used for book illustrations more largely than they are at present.

§ III. Chromoheliography.

In chromoheliography we have a problem, the solution of which is much less advanced than that of photographic engraving, but which has nevertheless been the object of interesting experiments. We here deal with the reproduction of colour in images with no intervention save that of light, hence this particular application of the photographic art and of physics has been named chromoheliography.

When we look on the screen of the camera obscura at the landscape which is there reproduced in miniature, all the objects represented are depicted as in a mirror, with all the variety of shades and colours with which they are clothed in nature. It is natural that the wish should have arisen to fix this faithful image; but how? Does there exist a sensitive substance which not only can receive different impressions according to the colour of the luminous rays which strike it, but can retain this exact impression and give it to the eye the same as it was received?

This is the whole extent of the problem. It is far from being solved; but what has been achieved in this direction encourages the hope that the solution is not impossible.

In 1848, M. Edmond Becquerel announced to the Academy of Sciences that he had succeeded in fixing on a sensitive plate the solar spectrum with all its colours. He took a silvered plate, on the surface of which he formed a coating of sub-chloride of silver by immersing it in a solution of hydrochloric acid, acted on by the galvanic pile. When the colour of the sensitized coating attained, for the second time, a violet rose tint, he submitted it to the light of a spectrum obtained by the aid of a lens. "The sensitized coating was then impressed with red on the red, yellow on the yellow, green on the green, blue on the blue, violet on the violet. The reddish tint turns to purple at the extreme red and even extends beyond the line A of

Fraunhofer; the violet tint continues beyond H, gradually becoming paler. On continuing the action of the spectrum, the tints darken and the image eventually takes a metallic gloss; the colours have then disappeared."

The colours thus obtained could be preserved for some time in the dark; but they disappeared in daylight, and M. Becquerel could not succeed in fixing them.

It is a curious thing that white comes out black on the plate; but by submitting the latter to a temperature of 80° to 100°, the white light produces a white impression.

By placing a coloured engraving on the chloridized plate, M. Edmond Becquerel also obtained the reproduction of the colours of the picture by a sufficiently long exposure to the solar light; but he had to interpose a screen of sulphate of quinine to impede the action of the ultra-violet rays, which would have given the whole picture a grayish tint.

M. Niepce de Saint-Victor, improving on M. Becquerel's method of working, succeeded in reproducing the colours of pictures and even in obtaining black in conjunction with the other colours. The sensitized coating then requires a particular preparation. The blue-violet tinted surface is covered with a varnish of dextrine and chloride of lead. "I have reproduced by contact," he says, "a coloured engraving representing one of the French guards: the different colours of the uniform were reproduced; the black hat, as well as one of the gaiters (the other had been cut away and covered over with white paper), impressed the plate very distinctly, giving a more or less dark tint according to the preparation of the plate. The cutting-out showed white."

M. Niepce de Saint-Victor also found that the greater or less concentration of the solution of the chloride used in preparing the sensitized plate, influences the development of different colours. With a weak solution, yellow comes most readily; by augmenting progressively the dissolved chloride, he obtained blue-green, then indigo, then violet; and finally the less refrangible colours, orange and yellow, require the most concentrated solution. Another interesting result is this: the metallic chlorides exercise an analogous influence, or rather one depending on the colour given by each of them to the flame of alcohol. Hence, if we add to the solution a certain quantity of

chloride of sodium, which gives a yellow flame in the alcohol, it will be the yellow which will be most intensely developed; with the chloride of copper it will be green, with the chloride of strontium it will be red. Unfortunately these results, which are most interesting in a scientific point of view, have not been of practical use in photographic art. These colours given by the light only remain on the sensitized coating as long as they are in complete darkness; they can only be hastily examined, and they vanish in the light of day. Every effort made as yet to fix them has failed.

Among the attempts made in the same direction as that of M. Ed. Becquerel and M. Niepce de Saint-Victor, we may mention those of M. Poitevin, who obtained most of the colours of the spectrum, chiefly red, orange and yellow, on a paper charged with hyposulphite of silver, and covered over with a coating formed by a solution of an alkaline bichromate, mixed with a strong solution of sulphate of copper, and a solution of five per cent. of chloride of potassium. With the paper thus prepared and placed for ten minutes on a painting on glass, the colours were reproduced; but they faded away in the light.

Some investigators, unable to solve the problem in its integrity, have tried another plan. Inspired no doubt by the processes of chromolithography, they sought to obtain the colours separately, the combination of which would reproduce the colours of the objects. With three proofs, one of which would give red, the second yellow, the third blue, they hoped, by superposition or union, to obtain the compound colours. Two photographers, Messrs. Cros and Ducos du Hauron, severally pointed out this solution; but the latter alone has put it in practice. His process is thus described in M. Davanne's *Photographic Annual*:—

First of all three negatives are struck off, one of which is to serve as the red positive, the second the yellow, and the third the blue. "To make the blue negative, all the simple and compound blue tints must be extinguished in the subject to be reproduced, that they may have no action on the sensitized coatings; for this the proof has to be obtained through an orange coloured glass. After a very long exposure, an image is obtained in which the blues have exercised a very feeble influence on the sensitive coating, while the yellow is sufficiently prominent. The proof representing

the red negative is obtained by extinguishing the red rays by means of a green glass. The yellow proof is obtained by the intervention of a violet glass.

"These three negatives each serve to produce a positive proof, which may be obtained by the mixture of gelatine and bichromate of potash, with the addition of the necessary colouring matter, either red, yellow, or blue. The gelatine surfaces being prepared with transparent colouring matters, are printed under their corresponding negatives. That obtained with the blue-violet glass is placed on the yellow film, and by washing, a monochrome yellow proof is obtained; the negative obtained with the green glass is put on the red gelatine; that which resulted from the interposition of orange-coloured glass is placed on the blue gelatine. After exposing, developing, and drying the images, they are superposed, and give a coloured proof with the whole series of different shades and tints"

The proofs obtained by M. Ducos du Hauron show the correctness of his theory as carried out in his process. It is therefore an interesting result, but it still leaves unsolved the problem of fixing the colours.

§ IV.—Application of Photography to the Arts and to the Natural and Physical Sciences.

Such, in their most essential features, are the processes of this new art, one of the most original applications of the laws of physics combined with those of chemistry. Such are the chief advances made since Daguerre's time. We have only given an idea, be it understood, of the different methods which constitute practical photography, by trying to connect them with the principles of science; but there still remains much to be elucidated as to the reactions determined by the influence of the luminous waves, and it is on physicists and chemists more than on professional photographers, however talented, that the task of dissipating the obscurity which still reigns on this point devolves.

Photography, as it exists at present, has rendered the most eminent services to the arts and sciences. In a certain point of view it is an art which requires, in those who cultivate it, independent faculties of technical skill. The choice of subjects, in portraits as in landscapes,

the arrangement of *pose*, the study of the most favourable conditions of light for a really artistic reproduction, presuppose faculties which education may develop, if the real feeling pre-exists, but which are not given to all photographers, however familiarised they may be with all the necessary manipulations.

As to the services rendered by photography to the arts and sciences they are, we repeat, incontestable. Thanks to this discovery, the productions of art in every country in the world are reproduced with an irreproachable fidelity. This is clearly evident in views of monuments of architecture, as well as in works of sculpture. All objects in relief present a clearness of detail, an accuracy of drawing, which engravings can rarely equal, and never surpass. Moreover, photographic views of this description are the most useful auxiliaries to the draughtsman, the engraver, or the painter. It is not quite the same for painted pictures, because the different colours have not the same photogenic action on the impressible substances : thus the blues come out lighter, the yellows and greens are often black ; so that the reproduction of a painted picture, however satisfactory in drawing, is generally mediocre as regards colour. Copies of this description have no less the charm of a fidelity which painted copies cannot equal as regards the drawing and the general effect.

Facsimiles of ancient or rare engravings, of which the original blocks have disappeared or are worn out, are admirably reproduced by photography, and, here again, this discovery renders and will still render signal services to artists and amateurs. The exceptions which we must make, in a purely artistic point of view, exist no longer if we pass on to the applications of photography to the positive physical and natural sciences.

Geography, ethnology, anthropology profit most. The reproduction of sites, of mountains, of their outline, of their relative positions, that of towns, monuments, harbours, inhabitants of divers countries, their costumes, objects of every description, implements, weapons, &c., are henceforth secure from the unskilfulness of artists, the incorrectness, sometimes involuntary, sometimes wilful, of narrators and travellers, and they prevent all exaggeration, flattery, or calumniation. What a valuable resource, above all, for anthropologists, who can thus collect the true types of all the human races, and of their innumerable varieties.

Natural history, medicine, anatomy, and physiology are no less indebted to photography, through the infinite resources which it provides for their special study.

Preparations which can only be preserved at a great expense, the true forms of vegetable, animal, or human anomalies, once fixed by light, with their most minute peculiarities, thus multiplied for science, will in the same way multiply the subjects for study by serving as a sound basis for the discussions of scientific men. Thanks to photomicography and the enlarging processes, an immense assistance has

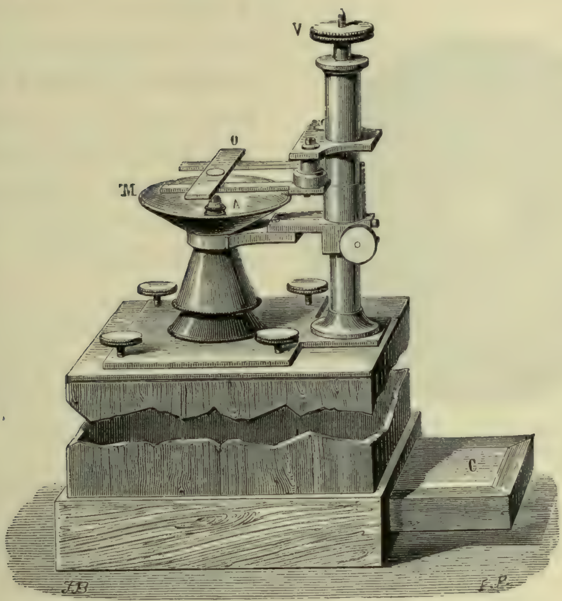

FIG. 225.—Photographic microscope.

been and will still be rendered in the study of the animal and vegetable tissues, and of the infinitesimally small creatures revealed by the microscope. What we have said for man and the human races may be repeated for the endless varieties of animal and vegetable life, which the most talented draughtsmen can doubtless delineate, but not without a great expenditure of time and toil. Besides, these very talented draughtsmen are rare. It is not every explorer, every traveller in untrodden or unknown lands, who can pretend to possess this difficult art. Furnished with a photographic apparatus and the

necessary appliances, he can obtain, with a comparatively trifling expenditure of time and labour, a considerable mass of documents, which will have, beyond everything, this exceptional value, that the fidelity of the agent who has portrayed and fixed them, namely, light itself, cannot be questioned.

Photography can pass from the infinitely small to the infinitely great. The celestial phenomena have come under its action—The spots in the sun, the mountains in the moon, eclipses, and the physical peculiarities which they have offered. The planets and starry constellations have been attempted. All has not yet been said of the services which this wonderful art may one day render to astronomy; but what has already been done in this direction has been exaggerated, and, at any rate, the true *rôle* of astronomical photography, and the influence it may have on the progress of science, have not always been properly understood. We think, therefore, that it will not be out of place to define them more clearly. We cannot do better than quote verbatim what was said on this subject at a Conference, in 1868, by an astronomer whose science and experience are only equalled by his modesty, the author of the *Selenographie,* the venerable Mædler.

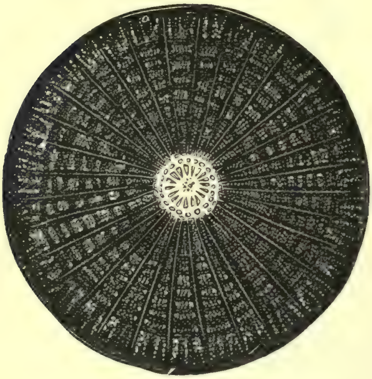

FIG. 226.—Minute disc: *Arachnoidiscus.* Facsimile of a microscopic photograph.

"Most of those who hear me," said he, "can remember that immediately after the discovery of photography such hopes were expressed as were only equalled by those of Descartes and his contemporaries after the discovery of astronomical glasses. They pitied the unfortunate men of science who had passed their whole life without interruption in observing, measuring, drawing. Not only were they going to do the same thing without trouble and in much less time, but they would obtain better results, more exact, and more in detail than heretofore. What has cost me seven years, the determination of the surface of the moon, was to be much better done in seven seconds.

"At the present day thirty years have elapsed since the discovery of Daguerre; how have these ambitious hopes been realised?

"Warren de la Rue in England, William Cranch Bond in America, and others, have bravely put their hand to the work. They have adapted powerful astronomical glasses to photographic apparatus, and they even succeeded in giving their apparatus, during the short interval necessary for producing proofs, the same movement as the celestial bodies whose image they were trying to see. Thus the moon has been photographed in her different phases; but the details have remained far below those to be discerned by an able observer. Bond devoted his study to the fixed stars, and he employed a telescope capable of showing stars of the fourteenth magnitude; but he could only obtain feeble and scarcely visible images of stars of the fifth magnitude.

"We might certainly allude to some very valuable drawings which we owe to astronomical photography; but it is not the details of the starry sky that we can gain and preserve by this means: it is rather the phenomena presented by objects long known and giving a powerful light.

"I will first allude to the spots on the sun, the reproduction of which only requires a fraction of a second, and with a very accurate result. Yet, even in this instance, the details are far inferior to those which can be reproduced by able observers accustomed to these phenomena; but a very important point of its kind is gained, an image of the sun at a certain moment, and, if I may be permitted to use an expression of Sir John Herschel, the sun is forced to write for us his own history.

"These experiments will be, or, to be more exact, have already been very useful, particularly in total eclipses of the sun. There is no draughtsman, however expeditious he may be, who can do in two or three minutes—the ordinary duration of the phenomenon—what Warren de la Rue did in Spain on the last occasion of a solar eclipse, for, supposing all to have been prepared beforehand, one may obtain not only three, but twelve or fifteen images of a phenomenon which disappears so rapidly. For the planets, even the large ones, photography is of little use, and will teach us few new things. It is even less useful when applied to the stars. The groups of the Pleiades and of Orion have been photographed, and one could recognize the

constellations in the images thus obtained ; but a clear eye, without glasses, could see more in the sky than could be shown by photography. We congratulate ourselves on the new method of study possessed in a very complete manner by several observatories, among which we will mention the observatory of Wilna; but we neither anticipate, by its intervention, any enlargement in the sphere of action of practical astronomy, nor an overthrow of the art of taking observations, such as resulted from the invention of astronomical telescopes."

Plate XIII., which represents two identical portions of the moon, will enable us to testify to the correctness of Mædler's judgment: one is a facsimile of the selenographical map drawn by the illustrious astronomer; the other is the enlarged reproduction of a fine lunar photograph taken by Mr. Warren de la Rue. In the latter the relief of the surface is admirably realised by the contrast of the lights and shadows ; but one cannot distinguish a host of topographical details of great interest which the astronomer, aided by powerful instruments, has accurately delineated, and which convert his beautiful map of the moon into a valuable monument for future selenographical researches.

Although there is still something to be said for the accuracy of the position taken up by Mædler, the importance of photography in astronomical work is being more and more acknowledged as the processes are developed, and for such observations as require daily registration, such as photographs of the solar surface, it is already invaluable.

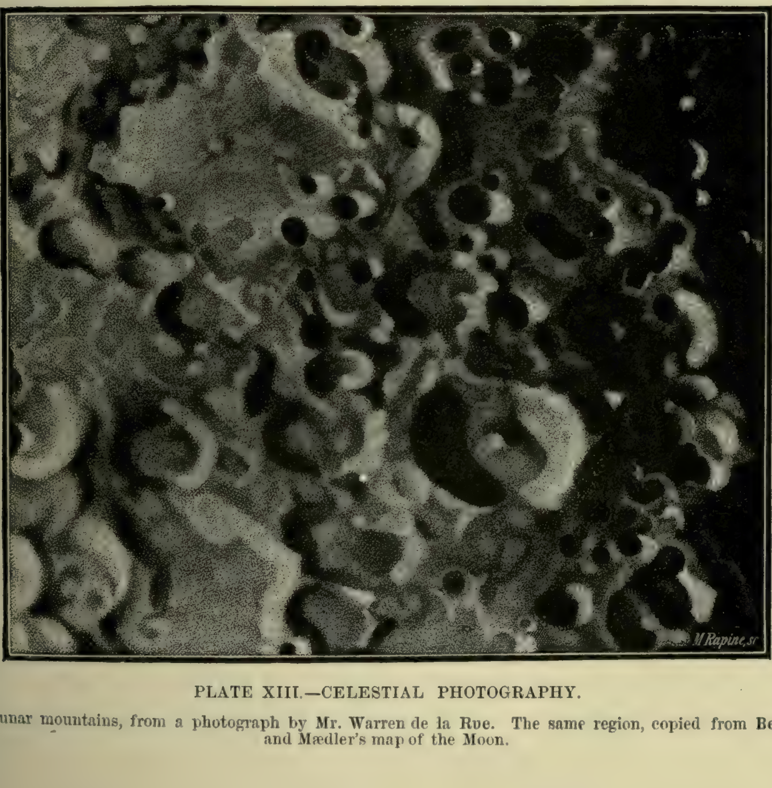

PLATE XIII.—CELESTIAL PHOTOGRAPHY.

Lunar mountains, from a photograph by Mr. Warren de la Rue. The same region, copied from Beer and Mædler's map of the Moon.

BOOK IV.

APPLICATIONS OF THE PHENOMENA AND THE LAWS OF HEAT.

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CHAPTER I.

THE ART OF WARMING.

§ 1.—Ancient Methods of Warming.

Of all the varying conditions which are hurtful to our health, or restrict us, to a certain degree, in the full use of our physical and intellectual faculties, sudden changes of temperature and the extremes of heat and cold are among those which affect us the most, and against which it is the most necessary for us to be on our guard. The regions of the earth, where reigns, as the old phrase runs, a perpetual spring, are few, and but little inhabited. Even in the temperate zones there is a wide interval between the summer's heat and the winter's cold. In proportion, too, as civilisation embraces larger and larger areas both in the New and the Old World, so voyages multiply, fresh countries are colonised, and man is forced to live in places where the extremes of temperature, unless their effects are overcome, would render his acclimatisation difficult, or at all events dangerous to his health. Hence the need of combating these effects, whether dangerous or simply disagreeable, by appropriate methods, and of regulating the use of the latter by the laws of physics and hygiene.

These methods are of various kinds. They may have reference to our houses, our clothes, or even to our meat and drink; and it is

obvious that we may arrange them in two distinct classes, according as they are intended to protect us from the extremes of heat or the extremes of cold.

Let us consider first the art of warming, which is the chief necessity for the inhabitants of the frigid and temperate zones.

The most natural as well as the most primitive method of

FIG. [illegible] making fire.

protecting oneself from the cold, is to light a fire and expose oneself directly to its influence. Our ancestors of the Stone Age doubtless knew no other way: they lighted in the open air the fires which served for the cooking of their food; and so do still not only many savage races, but even our own soldiers when out on a campaign. Nevertheless a great advance was soon made upon this commencement of

the art of warming, which consisted in placing the fire under cover in the primitive habitation, at first in caverns, but afterwards in huts of wood, branches, or stone.

FIG. 228.—A Spanish brasero.

What length of time elapsed before the invention of chimneys? Many centuries, no doubt; and the smoke escaped from the hut, either by the single opening which served at once for doorway and

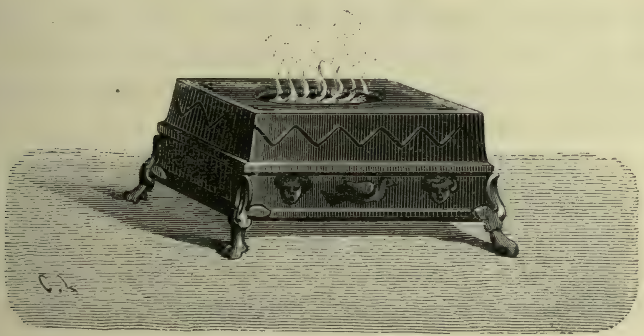


FIG. 229.—A Roman foculus.

window, or, as among the Gauls, the Germans, and even now among the Esquimaux and a score of other semi-savage tribes, by a hole made in the upper part of the roof.

But we have no intention of tracing here the history of the art of warming, nor of inquiring whether the ancient Greeks or Romans were acquainted with chimneys, or if, on the contrary, these useful appliances only made their appearance during the Middle Ages in the houses of Western Europe. That improvements which in these days appear so simple should have been so slowly introduced is nothing extraordinary when we consider that our present civilisation has advanced from the South and the East towards the West and the North. The Greeks used to pass a great part of their life in the open air, and the mild climate of the Islands of the Archipelago

FIG. 230.– Warming among the ancients. Grecian tripods.

and of the Peninsula of Greece did not render necessary any exceptional precautions against the cold of winter. They were satisfied to moderate the temperature of their houses by placing braziers upon tripod-stands with lighted coals beneath the warm ashes—a method of warming which was neither very efficacious nor very healthy. The *tripods* of the Greeks and the *foculi* of the Romans are still found under the name of *braseros* in southern countries, as in Greece, Italy, and in Spain.

We come then to the appliances for warming made use of in modern times, and we will begin with fireplaces.

§ II.—Warming by Means of Fireplaces.

This is still the method of warming most commonly adopted in England and France. The hearth, where combustion takes place, is formed of a cavity excavated most commonly in one of the principal or bearing-walls of the house. It is surmounted by a cylindrical or prismatic passage, by which the smoke and the other gaseous products of combustion escape, and the outer orifice of which is raised above the roof.

In ordinary fireplaces combustion takes place at the expense of the air of the room, which thus loses its oxygen, and therefore requires to be incessantly renewed. This renovation is effected by a process, the phenomenon of which we are all familiar with under the name of a *draught.* This is nothing else than the ascending motion of the air and warm gases which escape from the grate. When the fire is first lighted the outer air filling the chimney and the air of the room are in equilibrium. The heat of the fire warms the lower layers of air, which become less dense, and therefore tend to rise, and in fact do rise. The colder air of the layers above fills the vacuum thus caused and produces a descending current, which is at first stronger than the ascending, and so very often the smoke is driven back into the room.

As soon, however, as the column of warm air rises to the outer opening of the flue and fills the whole chimney the ascending vertical current gains the mastery, and the draught produces its complete effect; but always on one condition, and that is, that the air of the room, in proportion as it yields its oxygen to the fire, shall be as constantly replaced by fresh supplies. If from any cause this renewal cannot be effected, the force of the draught diminishes by degrees, and with it the activity of combustion. One result of this is that the smoke is driven back, and another, that the air of the room is vitiated, by being deprived of its oxygen, which is replaced by irrespirable or poisonous gases, such as carbonic acid and carbonic oxide. A draught, then, is as necessary for health as for the proper working of the fireplace.

Now how is this last condition of which we have been speaking

to be fulfilled? Where is the fresh air to come from which is to replace that which is taken from the room by the combustion kept up by the draught?

In olden times it was through chinks in the doors and windows that this fresh supply was obtained. The fireplaces then almost always smoked when these openings were properly closed, as they should be in newly built houses. At all events a serious inconvenience arose from the currents of air, which were very disagreeably felt by persons sitting in the chimney corner—and every one knows how much draughts have had to do with rheums, or rheumatic affections—and even in our present houses there are not wanting instances where the fireplaces constructed in the old way produce the same results, that is to say they leave us the choice between disagreeable smoke and unhealthy draughts.

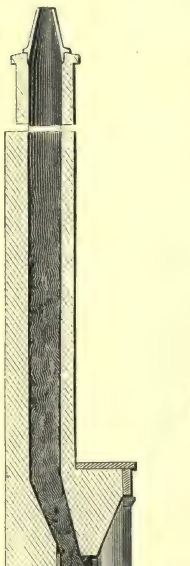


FIG. 231.—Draught in an ordinary fireplace.

The construction of a fireplace according to the requirements of science is an art which does not date very far back. In the reign of Louis XIV., not only in private houses, but even in the palaces of the king, a poor degree of warmth was maintained by making very large fires. To escape the draughts they used screens, and even this was not always sufficient, since Louis XIV. himself in winter time used to remain in his apartments snuggled up in a sort of box like a carriage or sedan-chair, which prevented all access of air. Besides this, as we shall see, it was not only the arrangement of the draught that was defective, the utilisation of the heat developed by the combustion was as bad as it could be.

How in fact does the fire in the grate warm the room and the things contained in it? In the first place, directly by the radiation from the flames and glowing coals. In the old fireplaces, therefore, where the fire was at the bottom of a large square cavity bounded on either side by jambs, and above by a funnel or a shelf, all of which presented obstacles to radiation, a small part only of the heat rays were utilised.

PLATE XIV.—A FIREPLACE IN THE MIDDLE AGES.

At the present time, or rather since the time of Gauger[1] (1713) and Rumford, the fire has been placed forward in such a way as to afford a wider scope for direct radiation. Besides this the inner sides of the jambs are cut off by surfaces of glazed earthenware or steel placed obliquely, or sometimes in the form of a parabola. In this way the rays which would not otherwise reach the room are reflected and contribute to the warmth.

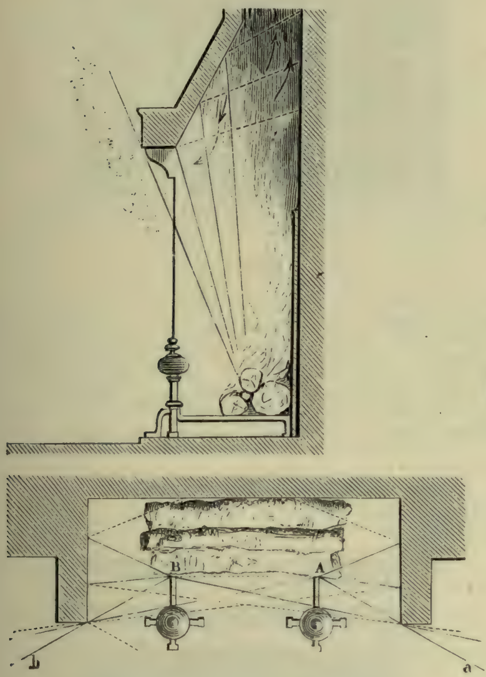


FIG. 232.—An ancient fireplace: utilisation and loss of heat.

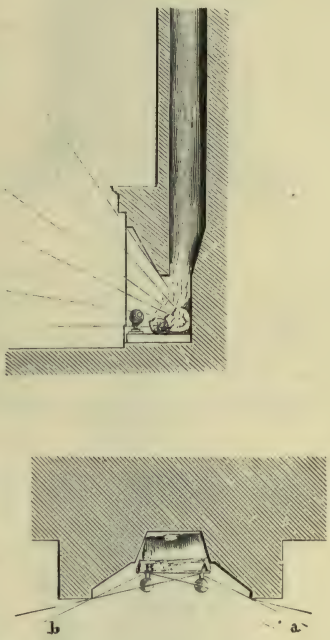


FIG. 233.—A modern fireplace: radiation of the heat.

The opening of the grate is contracted above to the point where the chimney commences, which has the double advantage of increasing the draught and of preventing the smoke from escaping into the room. This effect is further increased by the use of *movable blowers,* which are pieces of sheet iron which can be raised or lowered

[1] Author of a work, of which the following is the title: *La Mécanique du Feu; ou, L'Art d'en augmenter les Effets et d'en diminuer la Dépense: Traité des nouvelles Cheminées qui échauffent plus que les Cheminées ordinaires, et qui ne sont point sujettes à fumer.* Paris, MDCCXIII.

at pleasure in front of the fire, and are advantageous substitutes for bellows.

The warming of an apartment by means of a fireplace is accomplished not only by radiation, but also by convection: that is to say,

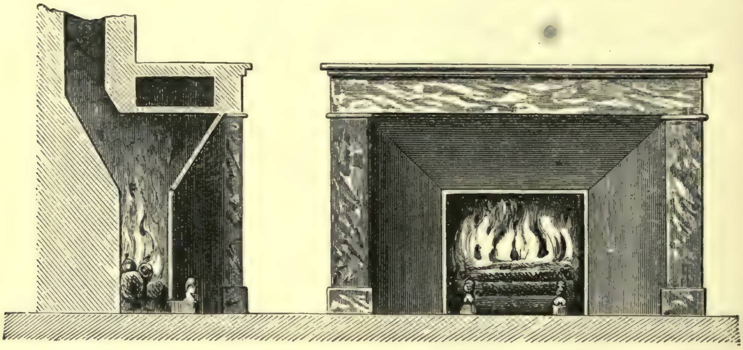


FIG. 234.—An ordinary modern fireplace.

by the transport of warmed particles of air, which rise towards the ceiling, and are replaced by the cold air, which is constantly drawn in from outside. In this way there arises a natural ventilation, generally more than sufficient from a hygienic point of view; but

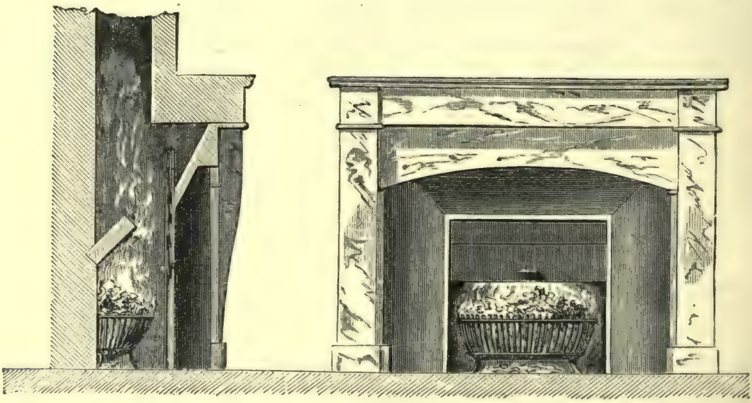


FIG. 235.—Modern fireplace with movable blowers.

another result is that the fresh air, being cold, has to be perpetually heated by the fire, the warmth of which is thus disadvantageously used. Moreover, since the chimney contains a great quantity of

the warm gaseous products of combustion,[1] the calorific effect of these fireplaces is extremely feeble, and we are led to seek more rational arrangements, and to invent those which are known as *ventilating fireplaces*.

§ III.—Ventilating Fireplaces.

The principle of the ventilating fireplace is as follows:—Instead of drawing from outside, through the chinks of doors and windows, or even by ventilators and side-conduits, the air which is required for the draught, and indispensable for the renovation of the vitiated air of the room, it is attempted to prevent the fresh cold air from entering till after its temperature has been raised by means of the fire itself. The air from the outside is therefore made to circulate in the passages surrounding the grate, and when heated it is made to escape by ventilators into the room itself, and thus contribute to raise the temperature.

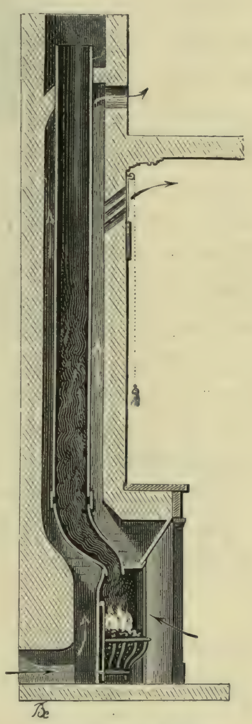


Fig. 236.—Douglas Galton's ventilating fireplace.

Various arrangements have been invented for this end. We will mention only two of the most simple.

In one (Fig. 236) the air comes from the outside by a passage which entirely surrounds the iron cylindrical flue, and also a part of the grate; it thus becomes warm, and rises to an opening made near the ceiling in the wall of the room. It is thus warm air, and at the same time fresh and unvitiated, that replaces what is consumed in the act of combustion or drawn off by the draught.

[1] According to General Morin, the air which leaves the grate is often at a temperature of 60°, 80°, 100° Cent. or more. The loss of heat amounts to $\frac{6}{7} \times \frac{7}{8}$ or more of this dispersed heat, and the calorific effect of an ordinary fireplace scarcely exceeds ·14 or ·12 of the heat developed by the combustion.

In the other form of fireplace the grate is an apparatus of cast-iron, and the flue is divided into several passages, along which the warm gases pass. Thus the whole apparatus helps to warm the chamber into which the outer air is received, and this, escaping into the room by two lateral openings, after having its temperature raised by contact with the sides of the apparatus, assists at the same time

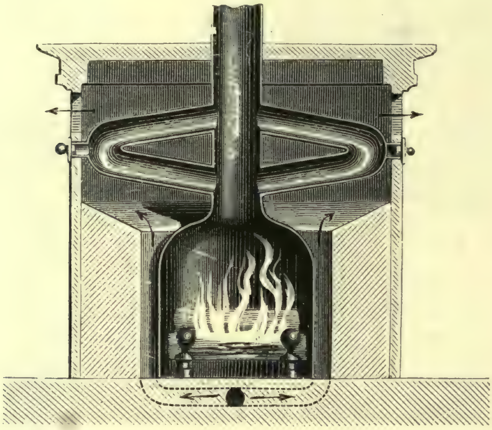


FIG. 237.—Ventilating fireplace, on Joly's system.

in warming and in ventilating the apartment. The heating effect of ventilating fireplaces is considerably greater than that of ordinary ones. It may reach as much as 30 per cent. of the heat developed by the combustion.

§ IV.—STOVES.

Stoves only differ in reality from fireplaces in this one respect. They are warming apparatus placed in the middle of the room that has to be warmed, instead of being set back against, or even ensconced in, the masonry of the walls. The consequence is that the warmth of its sides is communicated in every direction to the air of the room by radiation; and in this way the heat of the grate is much more completely utilised. The principle of the draught is the same, but

as the grate is only visible through a narrow aperture, there is scarcely any direct radiation from the flames or the glowing coals. The draught, on the contrary, is not diminished, but the amount of air passed through is relatively rather small, on which account the ventilation is generally insufficient. Hygienically speaking, stoves form an inferior means of warming to open fireplaces. Their forms are very varied, as well as the material of which they are made. Cast-iron stoves, owing to the great conductibility of the metal, are very quickly heated: their sides become red-hot, and, besides the insufferable heat thus caused, serious inconveniences are the result. One of these arises from the high temperature to which the air is raised, and the consequent dryness which affects the organs of respiration. This is remedied by placing a vessel of water upon the stove; this, by evaporating slowly, furnishes the required moisture to the air. Another inconvenience of more consequence has been recently noticed. The red heat of the cast-iron causes the formation of a gas, carbonic oxide, which is eminently poisonous, even when mixed with the air in very small proportion. It is thought by some that the glowing metal becomes permeable to the gases of combustion by a process of exosmosis or of dialysis, as explained by several writers, Graham, Henry St. Clair Deville, &c.; by others it is believed that the gas in question is formed at the expense of the organic particles of dust which become burnt by contact with the sides of the stove, or else by the decomposition by the glowing metal of the carbonic acid of the atmosphere. Whatever may be the cause of its formation, the phenomenon is proved, and with it the unhealthiness of cast-iron stoves, whenever, at least, they are heated till the sides become red-hot.

Stoves of brick, earthenware, and fire-clay, or even metal stoves which have a fire-clay lining to the grate, are without this inconvenience; but then they are heated much less quickly, on account of the feeble conductivity of the material forming the covering, although of course, for the very same reason, they preserve their heat much longer, and their use is much more healthy than that of cast-iron stoves, whose principal advantage is their being very economical. We have already said that ventilation with stoves is much worse than with open fireplaces. Their heating effect is as much greater. They

attain with ease to 85 or 90 per cent. of the heat developed by the combustion. Although the ventilation caused by the draught is altogether insufficient, according to M. Morin the air of a room warmed by a stove is renewed at the oftenest once in every ten hours.

Fig. 238 represents a heating stove, the arrangement of which is very advantageous, both with reference to ventilation and utilisation of the fuel. Ventilation is secured by an inlet air-pipe, which opens below the grate at A; a plug P allows the introduction of fresh air,

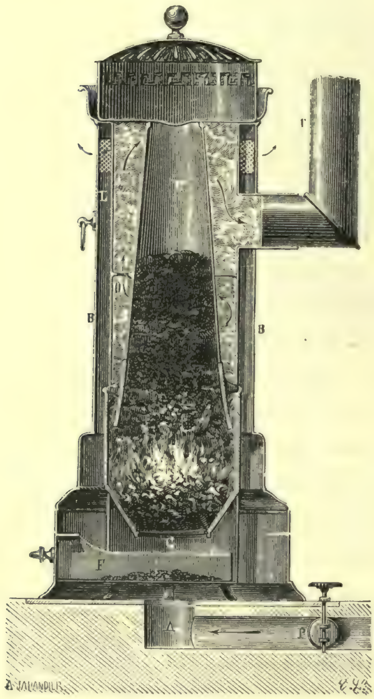


FIG. 238.—Heating and ventilating stove.

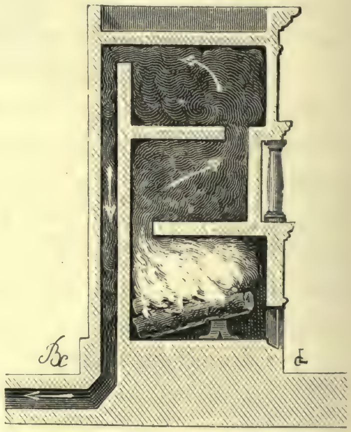


FIG. 239.—Section of a north country stove.

and consequently the draught to be regulated. The smoke, escaping by a flue-pipe at the side, warms the air in the chamber, whence it escapes by expansion through the lateral ventilators into the room. The outer covering B also prevents the injurious effects which might result from the overheating of the ircn case containing the fuel.

The charge of coal or coke is put in above by lifting the lid at the top.

In northern countries, such as Germany, Russia, Sweden, and Norway, the stoves are like pedestals, made of brick, and covered

FIG. 240.—A stove in Russia.

with earthenware or porcelain. The supply of air is obtained from outside by a pipe which enters the stove, and it is there warmed, together with the air within, by contact with the hot gases from the grate, and afterwards spreads itself, through the openings in

the sides, all over the apartment. In other cases (Fig. 239) the inside of the stove is simply divided into chambers or compartments one over the other, within which the smoke and the gases of combustion circulate. In this case it is simply by radiation from the outside that the warming takes place. In general it is sufficient to keep such a stove alight for a few hours in the morning, and then to close the apertures when the whole of the fuel is in a state of incandescence. The feeble conductivity of the clay or glazed porcelain which forms the outer cover then preserves the heat of the apparatus for the whole day.

CHAPTER II.

THE ART OF WARMING—HEATING APPARATUS.

§ I.—Heating by Hot Air.

The name "Heating Apparatus" must be kept for such arrangements as are designed to communicate to a distance the heat that is generated by combustion in a grate, and to spread it through a certain number of apartments, distinct from that in which the apparatus is fixed.

Some of them have more or less of a resemblance to ventilating fireplaces or stoves provided with inner chambers and openings for the hot air, since they too carry hot air to the various rooms that have to be warmed. These are hot air heating apparatus.

Others are constructed upon a different principle. The vehicle of the heat generated in the grate is in this case water, which, warmed by contact with it, circulates through conducting pipes in the thickness of the walls to all the places where the temperature is to be raised. These are the hot water heating apparatus.

And lastly there is a third system, in which the heat from the fire is made latent in the vapour of boiling water, which, by circulating in the conducting pipes, is cooled, condenses, and yields up all the heat given out by condensation to the surrounding objects and to the air in contact with them. These are steam heating apparatus. We will pass successively in review the apparatus of these three systems, and note their respective advantages and drawbacks.

The grates of the hot air apparatus are generally fixed in the cellars of the buildings they are required to warm, and in the centre of a chamber, the air of which is renewed by an opening from the outside, which has no direct communication with the fire itself, so that the smoke and other gaseous products of combustion have no

access to it. The pipe containing the smoke and gas is folded upon itself several times, or is divided into several parts, sometimes horizontal (Fig. 241), and sometimes vertical—an arrangement the object of which is the increase of the heating surface so as to utilise as much as possible of the heat obtained from the fuel. We see at once that for this purpose the vertical arrangement is by far the most advantageous, since the hot air in rising encounters nothing in its movement but the sides of the horizontal pipes, while it remains during the whole of its ascent in contact with the entire surface of the vertical pipes.

While the smoke and the gases are rising in the chimney, after having given up to the heating chamber a great part of their heat,

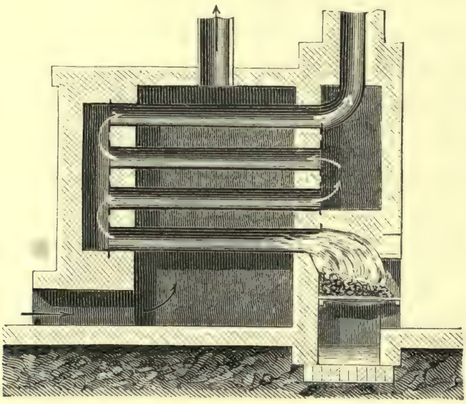


FIG. 241 —Hot air heating apparatus.

the air of the chamber thus heated rises through a central pipe divided into several others. These open severally upon the various floors and rooms of the building by apertures which may be more or less closed at will. The intermixture of this air with that of the room raises its temperature, but contributes nothing to the ventilation, unless this be secured by independent means. The heating effect of these apparatus may vary from 60 to 80 per cent.

The air, when it reaches the room, is often at too high a temperature. In order to obviate this it may be made on leaving the heating chamber to traverse a space to which the cold air has access by apertures provided with regulators, and can be so managed as to bring the mixture to a mean temperature say of 30° or 40° Cent. This method

of heating may be as injurious to health as stoves are and for the same reasons. The air they supply is dry, and the carbonic oxide and other deleterious gases may pass through the metallic pipes, and, finally evenness of temperature is far from being secured by this system.

§ II.—Hot Water and Steam Heating Apparatus—Heating by Gas.

In these last respects heating by the circulation of hot water is preferable. The temperature of the heated air is in this way more moderate and regular, and it is easy to account for these advantages.

The hot water boiler is fixed, as in the apparatus already described, in the lowest floor of the building. The fire is applied directly to heat the water of a boiler, C. This water, expanding by the elevation of temperature, rises by reason of its diminution of density through a vertical pipe which leads to the uppermost story. There it communicates its heat to the water of a reservoir or cistern, D, which acts as a kind of stove, since the heat from it radiates throughout the room and warms it.

A pipe descends from this reservoir to a similar one, F, on the floor immediately below, and so on till the water is returned to whence it started, and having grown cold by this incessant change, is heated again in the boiler, and there recommences the same movement.

It is easy to perceive that this circulation is continuous, that it begins, so to speak, as soon as ever the fire is lighted, and that it attains its maximum velocity as soon as the maximum difference between the temperature and density of the water in the boiler and in the uppermost reservoir is reached. The pipes which carry the water assist also in warming the rooms.

The uppermost reservoir is provided with an opening by which the water may be renewed, and from which the air disengaged by the heat or the steam arising from too great an elevation of temperature may escape.

Bonnemain, an architect of the 18th century, was the inventor of hot water heating, and his plan is still followed without material modifications. The water in this system has usually a temperature less than 100° Cent., and hence such apparatus are called low pressure apparatus.

Hot water heating may also be effected by bringing the water to a much higher temperature, say 300° Cent. In this case Perkins's high pressure apparatus is made use of, so called from the inventor of the system. In this the water circulates in pipes which have no communication with the open air, and are built in the thickness of the walls from one story to another, or beneath the floors, as in the low pressure

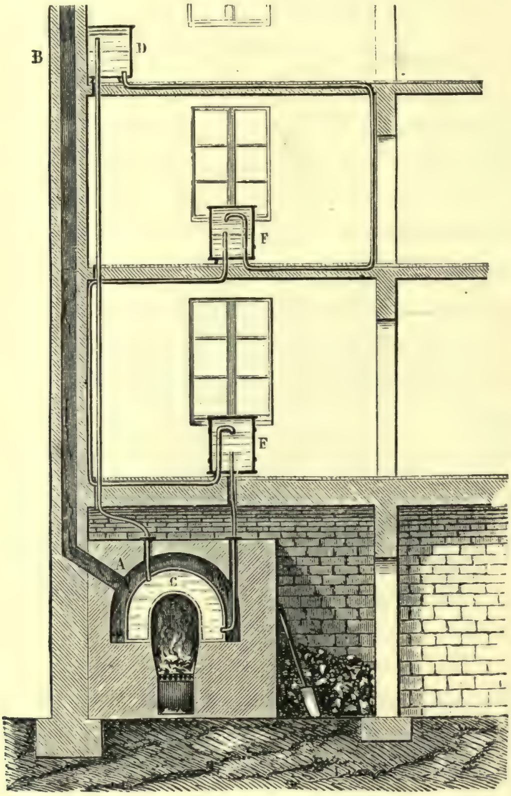


FIG. 242.—Hot water heating apparatus.

system, except that the tubes are constructed of stout iron and joined with great care, and are bent into spirals or coils, K, H, E (Fig. 243), on each floor, above the furnace, where they are subjected to the direct action of the heat, up to the rooms of the upper stories, where they fill certain spaces in the form of fireplaces or stoves, D, G, J, as in the represented figure. Above the coil in the uppermost story there is an expansion vessel *a*, containing a certain quantity of air which the

water compresses when its temperature rises, so as to avoid the effects of the expansion of the liquid and of the steam which is formed, the pressure of which latter may reach a considerable number of atmospheres.

The method of heating by hot water at high pressure is subject to serious drawbacks. It may cause a fire by setting light to the wood

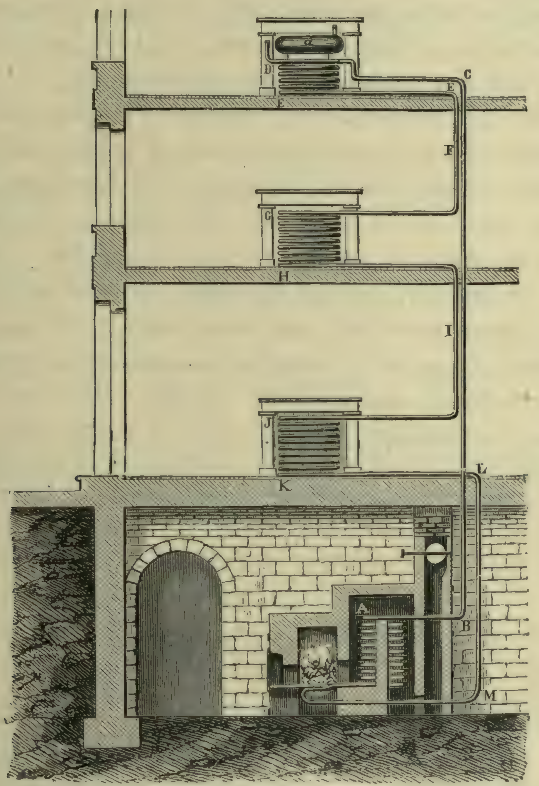


FIG. 243.—Perkins's high pressure system of heating by hot water.

adjoining the pipes. If the steam escape through any joints or cracks it might occasion explosions or dangerous scalds.

A third method, namely, that of heating by the circulation of steam, is based upon the great quantity of latent heat given out by steam in condensing. It requires pipes of but small dimensions; but its many drawbacks, the variations of temperature arising from any neglect in attending to the fire, the condensations, blows, fractures

and explosions that have arisen from this cause have caused the abandonment of this method of heating, which is only employed in factories where there is waste steam to utilize.

A mixed system, which appears to be very advantageous, has been invented by M. Gronvelle, an engineer. This consists in combining hot water heating with heating by steam. The latter is employed to heat the water contained in stoves fixed on the various flats or rooms of a building, like those described under the head of hot water apparatus open to the air. Hospitals, prisons, and large public offices can be healthily and economically warmed in this way.

There remains to be mentioned a method of heating which is useful in certain respects, and for special purposes, if not from an economical point of view, certainly for its cleanliness and handiness, but which can only be made use of in towns. We refer to heating by gas. But here we must not be misled; there is nothing but a substitution of one fuel for another, and the apparatus invented for the application of this system have only one object, namely, to make use of a certain number of gas jets to raise the temperature of stoves, cooking ovens, manufacturing apparatus, or the like. We merely mention these different utilizations, without speaking further of a method of heating which is based on the same principles as those in which coal, wood, coke, or turf, are employed as fuel.

§ III.—On Fuels.

This leads us naturally to say a few words on the fuels themselves and their relative value, with regard to the heat they develop; a question by no means unimportant in relation to heating apparatus.

Wood was the first fuel employed, and even now whole countries use no other. It is certainly one of the most agreeable, but it is also one of the most costly, except in countries covered with forests and remote from coal mines. Coal, anthracite, lignite and other mineral fuels, and coke, which is the residue left after the distillation of coal, are more and more frequently employed, as they afford a more economical method of heating. In some countries peat is used; in fact it is

always the vegetable kingdom, whether that of to-day or of ancient geological periods, that supplies the heat developed in the various apparatus we have passed under review. The gas that is also used as fuel, is but one of the ingredients of coal, and this simple fact proves why heating by gas is dearer than that by coal from which the gas is extracted.

We will now compare the heating powers of these different substances, according to the experiments of physicists. By the number of *calories* is meant the number of units of heat developed by the complete combustion of a kilogramme of each substance.

Fuels.	Calories.	Ratios of heating powers.
Coal	8,000	1·00
Anthracite	7,500	0·95
Coke	7,000	0·90
Lignite	6,500	0·80
Charcoal	6,000	0·75
Peat	5,000	0·60
Dry wood	4,000	0·50
Wood (20 per cent. of water)	3,000	0·38
Gas	10,000	1·25

Gas has the greatest heating power; next come coal and mineral fuels, then turf and wood, and moist wood is lowest of all.

We have seen further to what extent the heating apparatus, even the most improved, utilize the heat of combustion. The greatest part of the heat goes up the chimney.

If we would know the amount of heat lost annually in smoke we may take the consumption of fuel in Paris for example. The *Annuaire du Bureau des Longitudes* for 1872, gives us this consumption for the year 1869:

Wood of various sorts	994,057 steres.
Charcoal	4,902,315 hectolitres.
Coal, coke, turf	682,011,827 kilogrammes.

If we take a number less than the mean value of these various fuels the total value cannot be estimated at less than sixty-nine millions of francs. Twenty-five millions for wood, twenty-four millions for coal, and twenty millions for charcoal. But this last fuel is not used at all for heating purposes, and a considerable proportion of the coal is used for industrial purposes. The loss of heat is not

A A 2

very different for the three kinds of fuel, and we shall not be wrong in stating that sixty per cent. at least is lost in smoke without being utilized in any way. We have here then an annual loss of forty millions of francs which might certainly be considerably reduced if rationally constructed apparatus were everywhere adopted. The purse and the health of consumers would be thereby equally benefited.

What would be the result if we were to apply the same calculation to the whole of France, and to all the countries of the world?

CHAPTER III.

VARIOUS APPLICATIONS OF THE LAWS OF THE CONDUCTIBILITY OF HEAT.

§ I. DWELLINGS.

THE temperature of an apartment depends not only upon the heating apparatus which are placed in it, or on the heat which these may communicate to the air by way of radiation or convection, or any other mode of propagation; but it depends also, in the first place, on the temperature outside, and, in the second place, on the greater or less efficacy with which the walls or other protections oppose the passage of the heat from within outwards. This inevitable loss is more or less rapid according (1) to the thickness of the walls, or (2) according to the materials of which they are made, such as wood or other bad conductors of heat, or (3) according as the openings in them, closed only by glazed windows so as to admit the daylight, are more or less numerous, and present a greater or less surface.

Thick walls, made of materials which are bad conductors, have the double advantage of protecting the inmates in winter against the cold, and in summer against the heat. Stone and marble are in this respect less advantageous than brick, and much less than wood. In cold countries, as in Russia for instance, many of the country houses have their walls made of beams or thick planks, forming a double partition which is filled with broken materials, chopped straw, sawdust or dried moss. The air which is entangled in the interstices of this loose material forms with the partitions a combination very impermeable to heat, and a very bad conductor, and consequently an excellent protection against the low temperature of the outside.

But it is through the doors and glazed windows that in the day-

time the heat is most rapidly lost. An excellent method of securing oneself against this loss is the employment of double windows; the air which is imprisoned between the two slender partitions of glass is not renewed, and being a badly conducting substance, forms a protective covering, which the obscure heat of the inside can with difficulty pass through, while the luminous heat of the sun's rays on the contrary can penetrate with ease into the room. And thus we find the use of these media which are at the same time diathermanous for luminous rays, but athermanous for the rays of obscure heat.

This double glazing may be very advantageously employed in conservatories, where the plants require the full daylight, and which pine when the glass is covered by mats or other opaque material to protect them from the cold.

FIG. 244.– An icehouse.

Cellars are less exposed than the rooms of the upper stories to the exchange of heat which takes place between the inside and the outside or *vice versâ.* They thus preserve throughout the year a medium temperature, which varies the less as they are situated deeper. So they appear to be warm in winter and cool in summer. Though we cannot regard them as very healthy places for living in, they serve at least for the preservation of many things which are damaged either by excessive cold, or too great heat.

Ice-houses are a sort of cellar rather deeper than ordinary ones, dug in the ground, and cased inside by a wall of brick. Into this pieces of ice are thrown during winter time that they may be kept and used in the hot season. After the cavity is filled with fragments of ice, a certain quantity of water is poured in during severe frosts, which covers the whole with a layer of ice which prevents the access of the outer air. Straw is then heaped up over it and forms a

badly conducting layer. And then a roof covered with haulm and turf, and plantations of trees whose shade protects the ice-house from the rays of the sun, complete the process by which the interior of the cavity is rendered altogether impermeable to the external heat.

All these precautions are based, as we see, on the feeble conductivity for heat of earth, bricks, and loosely packed materials.

§ II.—Clothes.

From houses let us turn to clothes.

There are but few countries where clothes are not indispensable for protection against the weather, and especially against excesses of temperature, either in winter, or in summer. Man is not naturally protected against these excesses, and he may suffer greatly from them. He is not, as most animals are, provided with a covering of hair, or feathers, or down, or with a fleece more or less thick to protect him from the inclemency of the air,—and he must have recourse to his industry which can do no more than imitate nature in a more or less intelligent manner, according to the degree of civilisation he has attained to.

In the state of barbarism which characterised the first ages of mankind, a state of which we have still many remains, men could do no better than cover themselves with the skins of the animals they killed in the chase. This primitive garment is still that of many barbarous tribes. In polar climates the Esquimaux, the Lapps, the Siberians, clothe themselves in skins of bears and reindeers, which they cut in a rough sort of fashion. The hide is impermeable to moisture, but it is the covering of hair which forms the real protective layer against the cold, on account of its feeble conductivity for heat.

The temperature of the human body is pretty nearly constant in all climates and through all seasons. It is not modified by action from the outside, so to speak. "The blood of the Laplander," says Tyndall,[1] "is sensibly as warm as that of the Hindoo, while an Englishman in sailing from the north pole to the south finds his blood temperature hardly heightened by his approach to the equator, and hardly diminished by his approach to the antarctic pole." What forces us

[1] *Heat as a Mode of Motion.*

to use clothing is the disagreeable sensation we feel by the contact of our skin with cold air or air greatly heated by the rays of the sun, and the accidents which result to our health from the sudden change.

There are three things which render a fabric unsuitable for the conduction of heat;—the nature of the substance of which it is composed, the structure of the fabric itself, and its thickness. With regard to the first point, the following is the order in which the

FIG. 245.—The clothes of the Esquimaux.

various substances may be ranged, commencing with the most and ending with the least conducting. The results are due to the experiments of Rumford :—spun silk, cotton or wool, sheep's wool, taffeta, raw silk, beaver's hair, eider down, hare's skin.

We see from this that silk is a better conductor than wool, and as the fabrics of silk are of a closer set structure than woollen stuff, the

latter have a double superiority, *i.e.*, both as regards the fabric or as regards the material.

Daily experience confirms these inductive results, woollen garments are the best protectors against the cold, because they oppose the passage of heat from the body. These, too, provided the stuff be somewhat light, we should also prefer in summer for stopping the rays of heat, and preventing them from penetrating to our body. Besides this, we know that colour has also an influence, that black or sombre-coloured clothes give out the heat with greater facility than those which have a bright colour or are white. So that in winter the latter are preferable to the others, since they are less favourable to the loss of heat from the body. In summer, the heat without is less easily absorbed by white clothes than by dark, and they, in this case, are preferable to the others.

It is not the weight of the stuff that makes a garment hot, it is the divided structure of the tissue, an eiderdown quilt filled with fine and light down, is warmer than a heavy and thick counterpane.

We see from these examples, how necessary it is to take into account the various properties of bodies, their conductivity, their radiating, absorbing, and emissive power, in their ordinary applications to heating, to the construction of houses and to clothes; but we must also take health into consideration, which has to do not with physics but with physiology.

We seek for warmth in winter, for coolness in summer, but we must take care how far we go in this, in order that our health, which is the equilibrium of the functions of our bodies, may be kept in a good state.

§ III. Miners' Safety Lamps.

We saw in the *Forces of Nature*, that a metallic gauze placed above a gas flame prevents the combustion from being propagated above the gauze. The latter absorbs so much heat, that the temperature of the gas after passing through the little opening of the meshwork is not sufficient for ignition.

An illustrious English physicist, Davy, has made use of this important property to prevent accidents in mines, happening from the

inflammation of fire-damp. The miner's lamp which bears his name, has received various modifications and improvements since its first invention, but the principle of its construction remains the same.

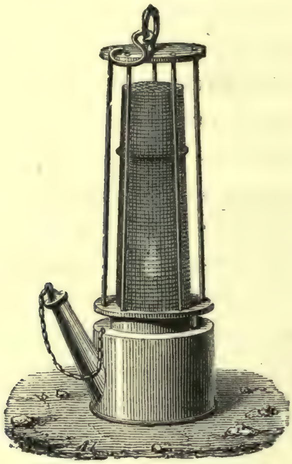


FIG. 246.—Davy's first safety lamp, with cage.

Figures 246, 247, 248, show several patterns. In all of them the explosion that would result from the introduction of an explosive mixture into the chamber where the lamp is burning is confined to that chamber itself. The envelope or metallic wrapper prevents the heat from being able to propagate itself outwards, and the miner is warned of his danger without having to suffer its terrible effects.

The new patterns of Davy's lamp give more light than the earlier ones, as the light burns in a glass tube. Moreover a particular arrangement prevents the imprudent conduct of the miners in opening these lamps, as they cannot do so without

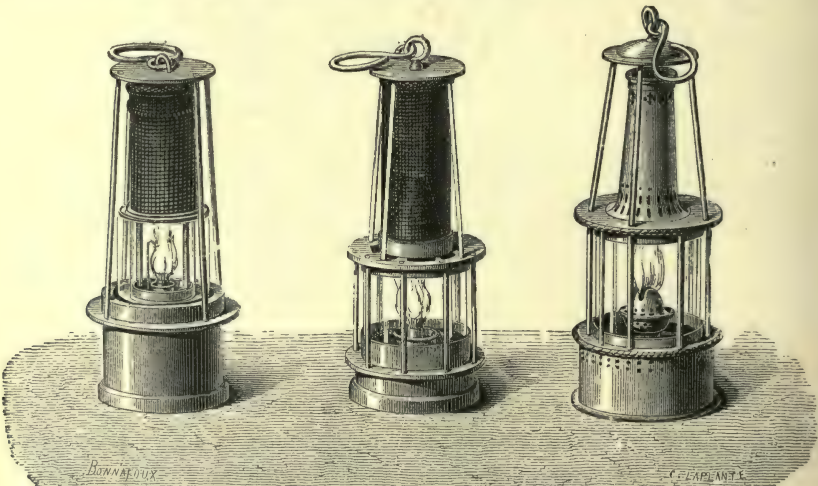


FIG. 247.—Miner's safety lamp, with cage and glass tube.

extinguishing it. The Combe lamp, which is represented in Fig. 248, is formed of a thick cylinder of glass surrounding the flame, above

which is a metal tube, further surrounded by a metallic network or trellis. The air required for combustion enters laterally, by openings

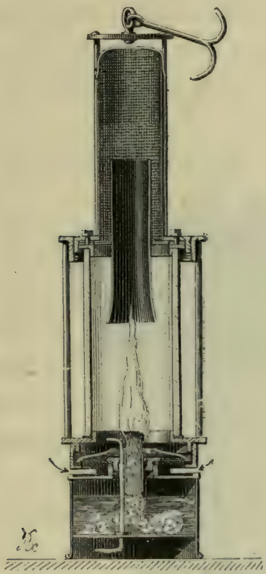


FIG. 248.—Section of one of Combe's lamps.

situated below the flame, which it reaches after having passed two thicknesses of metallic meshes.

§ IV.—Various Domestic Applications of Heat.

Certain customs based on the feeble conducting power of certain substances are well worth a passing reference.

Why are the hands of tools and utensils that we put on the fire made of wood? Why do we cover the handles of kettles with cane, or flat irons with leather or cloth? Because wood, leather, and cloth are very feeble conductors. It is for the same reason that these substances feel warmer than the metals, or than marble, when they are all in the same neighbourhood, where all the objects have one and the same temperature (less than that of the hand). The floor of a room does not feel so cold as the pavement, because the wood conducts heat less than brick, and a floor of pine feels less cold than one of oak for the same reason. In all these examples the contact of the hand

with bodies which are good or bad conductors causes a sensation of cold or of heat, because the exchange of heat which takes place in one direction or the other between these bodies and our skin is more or less rapid. The disagreeable feeling which arises from a scald is due to a too rapid exchange of heat bringing about the disorganization of the tissue. The same feeling may result from contact with an object which has a very low temperature, such is the feeling experienced on touching a piece of frozen mercury. In polar climates, the hand must not be allowed to touch metallic objects, which must be enveloped in cloth, or else thick gloves must be used.

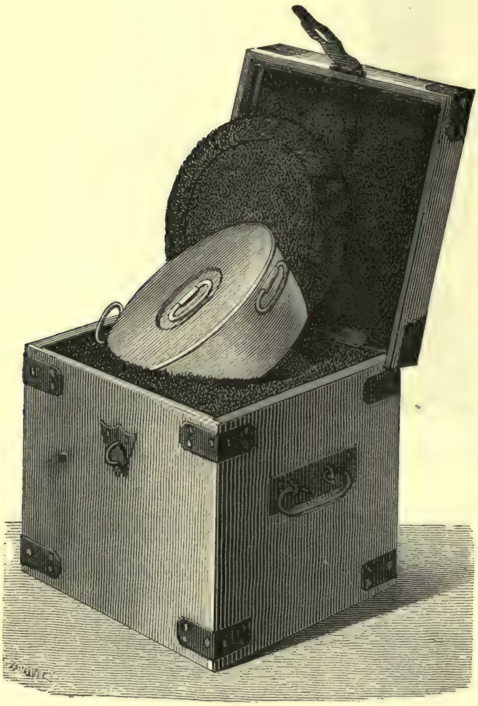


FIG. 249.—Automatic stewpan.

The feeble conductivity of certain substances, such as wood and felt, has been put to a curious domestic use.

The automatic stewpan, which was shown in the Paris Exhibition of 1867, and which is in use in the northern parts of Europe, is nothing else than a metal stewpan, into which the meat, vegetables, and all other ingredients of the stew, including water, is placed. The whole is put on the fire till it boils. The stewpan is then inclosed in a box that has the inside and lid lined with a thick layer of felt. The stewpan is also covered with a pad of the same material; it is closed hermetically and the utensil is then left to itself. The cooking continues, and is completed without fire, because, owing to the very feeble conductivity of the envelope, the heat within maintains a very high temperature for many hours; at the end of three hours it will have gone down, on an average, not more than 12° C.

CHAPTER IV.

VARIOUS APPLICATIONS OF THE LAWS OF HEAT.

§ I.—Burning Glasses and Mirrors.

Is it true that Archimedes, by the use of burning glasses, set fire to the Roman fleet, which, under the command of Marcellus, was besieging Syracuse? Is it true that Proclus did as much to the fleet of Vitellius during the siege of Byzantium?

These are questions which have been much discussed—which Descartes in his *Dioptrique* has answered in the negative—which the learned have solved in various ways, but which prove at least that the ancients were acquainted with the power of concave mirrors to reflect to their focus and condense into a very small space, the rays which emanated from a source of heat.

They were aware also of the effects of refraction through a mass of glass shape in the form of a ball or a lens, as is deduced from a very curious passage in the *Clouds* of Aristophanes.

The discussion of this point of history, interesting as it is from other points of view, has had the merit of inducing experiments which have placed beyond doubt the heating effects which may be produced by bringing the rays of the sun to the focus of a spherical or parabolic mirror, or to that of one or more lenses. The following are the principal results of some of these experiments recorded in D'Alembert and Diderot's *Encyclopædia*:—

"The most celebrated burning mirrors of modern times are those of Septala, Vilette, and Tschirnhausen. The burning mirror of Manfred Septala, canon of Milan, was a parabolic mirror which, according to Schot, could set fire to pieces of wood at a distance of fifteen or sixteen paces. The burning mirror of Tschirnhausen was at least equal

to that of Septala in size and power. We find the following in the *Acta Eruditorum* of Leipzig upon this subject:—

"'This mirror sets fire to green wood in a moment so that it cannot be extinguished by blowing violently upon it. It can boil water—as to cook eggs very quickly—or, if the water is left in the focus a short time it evaporates. It can melt in an instant a mixture of tin and lead three inches thick; these metals commence to melt drop by drop, then they run down continuously, and in two or three minutes the mass is pierced. It can very soon bring a piece of iron or steel to a red heat, and a little after can makes holes in it by the force of the fire. Copper, silver, &c. liquefy as soon as they approach the focus. It can also heat to redness like iron such substances as cannot melt, as stone, brick,' &c."

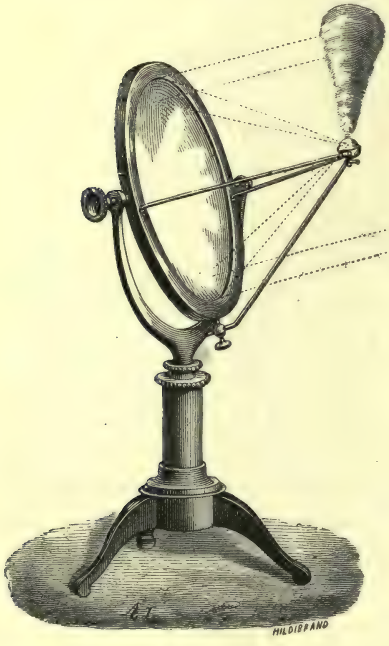


FIG. 250.—A burning mirror.

The mirror of Tschirnhausen was three Leipzig ells (or 1·69 metres) across, its focus was at a distance of 2 ells (1·13 metres), and it was made of thin copper.

A French workman at Lyons, called Vilette, made many large mirrors, one of which fell into the possession of the Academy of Sciences of Paris. It was a segment of a sphere of seventy-six inches radius, and therefore thirty-eight inches focus, its aperture was 1·27 metres; the substance of which it was formed was a mixture of tin, copper, and mercury. Its heating effects were comparable to those of the burning mirrors above described.

Buffon, too, in the last century, made some curious experiments by using for the concentration of the solar rays, not a concave mirror, but a series of plane mirrors so arranged as to reflect the rays of the sun to one spot. "He formed a large mirror composed of several

plane mirrors (he had 100) about half-a-foot square. Each of these mirrors was furnished behind with three screws, by means of which they might all be arranged in less than a quarter of an hour so as to reflect the image of the sun to the same spot. M. Buffon, by means of this compound mirror, had already been able to burn objects at a distance of 200 feet."—(*Encyl.*) In fact, at that distance he set fire to wood, at 140 feet he melted lead, and at 100 feet silver.

This illustrious naturalist and physicist attempted in this way to realize the hypothesis of a Grecian poet Tzetzes who believed that it was by this means that the Roman fleet had been destroyed at Syracuse. It was intended to show, by ocular demonstration, the possibility of Archimedes's invention, and the patriotic act attributed to the greatest geometer of antiquity. But Buffon had been anticipated without his knowledge by P. Kircher, and earlier still by Anthemius, the architect of S. Sophia, who must be considered as the original inventor of plane jointed mirrors.

Bernière constructed in 1759 a concave mirror of plate glass of 1·16 metres aperture, in the focus of which silver and even iron are said to have been melted in a few seconds and flints were softened and fell in drops like glass; at least this is so stated by Daguin, in his *Traité de Physique.*

We may now give some details respecting the heating effects produced by the refraction of a converging lens, or what is commonly called a burning-glass. The same physicists who experimented with mirrors tried also the effects of lenses of great dimensions. "The largest lens of this sort," says D'Alembert in his *Encyclopædia,* "was that of M. Tschirnhausen; the diameter of the lens was between three and four feet, its focus was at a distance of twelve feet, where the pencil of rays converged to a diameter of one-and-a-half inch, and in addition, in order to increase the power at the focus, the rays were converged a second time by a second lens parallel to the first, placed where the diameter of the cone of rays formed by the first lens was equal to the diameter of the second lens, so as to receive them all." The effects were similar to those of the burning mirror of the same experimenter.

One of the most curious experiments made upon the refraction of heat was that of Mariotte, who made a convex lens with a piece of ice obtained by freezing pure water deprived of its contained air. With this new kind of burning glass, Mariotte exploded gunpowder.

We must not omit to mention Bernière's burning glass, which was constructed on the same principle as that of Tschirnhausen, and of which Fig. 251 is a representation. The mechanism there shown was for the purpose of enabling one man to arrange both lenses at the same time, that the rays of the sun might always converge to the same point.

Burning-glasses have one disadvantage which renders them inferior to mirrors, namely, that in passing through a lens of any thickness part of the heat rays are absorbed by the glass. This defect Buffon

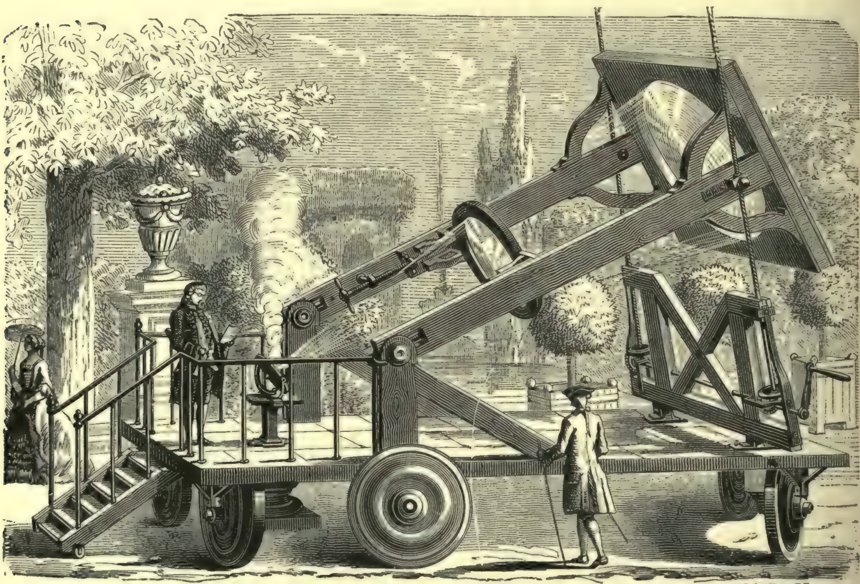


FIG. 251.—Bernière's burning-glass.

attempted to remedy by the intervention of polyzonal lenses, which consist of a series of rings, each of which forms part of a lens of constant focal distance, but of less thickness in the central portion. We have already described these lenses, which have been brought to perfection by Fresnel for the illumination of lighthouses.

Burning-mirrors and lenses have been applied to the solution of an interesting question in physical astronomy,—whether the solar rays which reach us by reflection from the moon have any sensible heat. A great number of observers, from Lahire and Tschirnhausen

up to Forbes and Tyndall, have obtained no results. But Melloni in 1846, and since then Piazzi Smith, Lord Rosse, and Marié Davy have perceived a sensible heating.

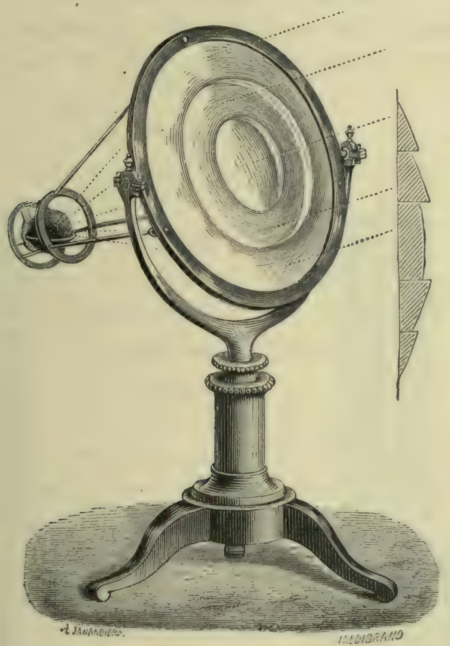


FIG. 252.—A burning-glass with polyzonal lenses.

§ II.—COMPENSATED PENDULUMS.

We have seen in the chapter on the applications of gravitation that treats of the pendulum, that one of the essential conditions of its employment in clocks is the constancy of the length of the rod, or rather of the distance between the point of suspension and the centre of oscillation.

Now this constancy supposes that the temperature at which the clock has been regulated with this pendulum itself remains constant. For if it rises, the material of which the pendulum is formed dilates, the pendulum is lengthened, and its oscillations are slower. If, on the contrary, the temperature falls, the material contracts, the pendulum is shortened, and its oscillations are quicker. Whence it

follows that a clock properly regulated at a mean temperature will lose in summer and gain in winter.

How is this defect to be remedied? or how may it be diminished so as to secure an invariable length of pendulum, and the isochronism of its oscillations? This is accomplished by availing ourselves of the unequal dilatation of various metals, and by compensating for the

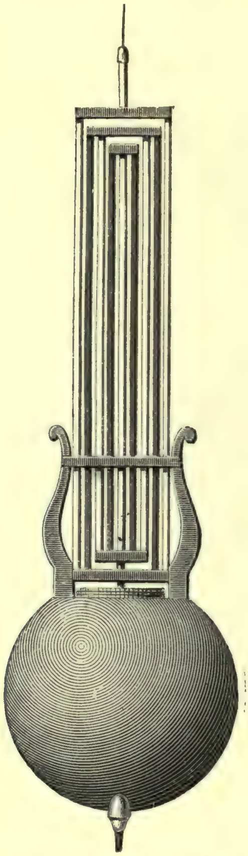


FIG. 253.—Gridiron pendulum.

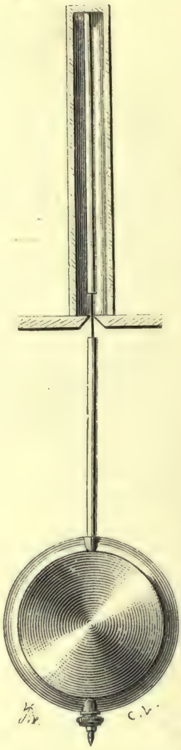


FIG. 254.—Leroy's compensation pendulum.

lengthening which would lower the centre of oscillation by raising that centre. Whence the name of *compensation pendulums* given to the various combinations which have been invented.

The method commonly used upon the Continent is the *frame* or *gridiron pendulum* invented by Harrison. The rod is formed by a series of alternate bars of brass and steel, jointed by transverse pieces, so that

the elongátions produced by the dilatation of the bars of steel tend to lower the centre of oscillation, while that of the brass in an upward direction tends, on the contrary, to raise it. The centre bar, which is made of steel, is the one which supports the bob, and it passes through holes in the cross pieces so as to be independent of them. The suspending rod is, on the other hand, fixed to the topmost piece which joins the outer bars. The lengths of these pairs of bars must be calculated from the coefficients of expansion of steel and brass in order that the lengthening due to the steel may be exactly equal to that due to the brass.

This affords only an approximate compensation, because the centre of oscillation of a compound pendulum does not coincide either with the centre of gravity of the bob, or with that of the whole apparatus. This compensation has therefore to receive its final adjustment by means of experiment.

Leroy's compensation pendulum (Fig. 254) consists of a brass tube fixed over a bevelled opening, giving passage to a steel rod, which is fixed within the upper end of the tube. This steel rod is in two parts, joined by a thin spring of the same metal, which is flexible at the top of the slit. The distance of this slit from the centre of oscillation gives the true length of the pendulum, the former being the true point of suspension. The method is not a good one, for if the slit is wide enough to allow the spring to slide freely, it is not close enough for accurate time-keeping.

When expansion takes place, the tube of brass rises, and the centre of oscillation follows the motion. On the other hand, the rod tends to descend, and the proper dimensions of the different parts may be easily calculated, so that there shall be compensation. This is rendered more complete by the same means as that adopted in the gridiron pendulum, and in all the other compensating systems, that is by trial.

We will notice two more systems besides these: Ellicot's plan, which is represented in Fig. 256, and Graham's, which was the first adopted (Fig. 255).

In the first of these, the iron rod *f*, which supports the bob, is furnished at the upper end with a cross-bar, to which are joined two brass rods *c*, *c*, dilating freely at their lower ends and supported upon two levers *a*, *a*, fixed to the bob. These levers act upon the bob by

the pivots *t*, *t*, and so raise it that the centre of oscillation tends to rise at the same time that the expansion of the suspending rod tends to lower it. The compensation is in this manner partly effected, and it only remains to complete it, as before, by trial.

Graham's compensation pendulum is that generally employed in England, and is formed of a steel rod, which supports at its lower end

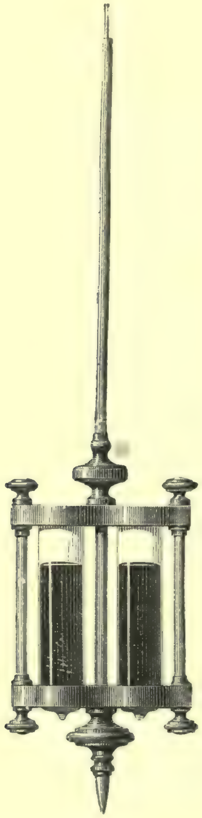


FIG. 255.—Graham's compensation pendulum.

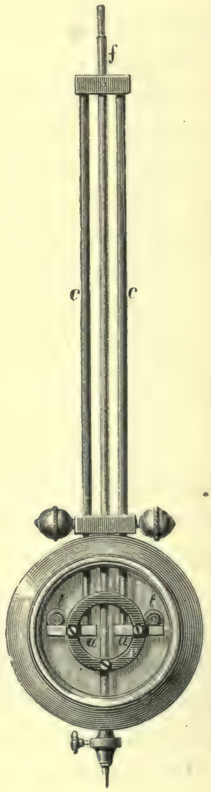


FIG. 256.—Ellicott's compensation pendulum.

a stirrup containing one or sometimes two glass cylinders, partly filled with mercury. When the expansion gives rise to an elongation of the suspending rod, and lowers the centre of oscillation in consequence, it is at the same time raised by the elevation of the level of the mercury in the tubes, arising from the same increase of temperature.

The amount of mercury required is easily calculated from a table

of expansions. Should any pendulum of this description be found either to be over- or under- compensated, the defect can readily be remedied by withdrawing or adding a little more mercury. The late Mr. Dent used iron jars to contain the mercury, as he found great difficulty in obtaining a perfectly true figure with glass ones.

There are other kinds of compensation pendulums, but they are all based upon the same principle, that is to say, on the unequal expansion of the solids or liquids composing them, and on an arrangement which in one way tends to raise, and in another to depress the centre of oscillation.

It is very important that a compensation pendulum should be so constructed that its different parts may all take up any change of temperature simultaneously.

The necessity for this was well brought out, during the time that the normal sidereal clock at Greenwich was under trial. That clock had been originally fitted up with a heavy iron jar mercurial pendulum, but it was found that the mercury being so little exposed in proportion to its bulk, lagged behind the steel rod, both in expanding and contracting, causing an error in the time of the clock by doing so. The clock was in consequence supplied with a new form of zinc and steel compensation. A central steel rod passes down to below the pendulum bob, carrying a collet, or shoulder, at its extremity. Upon this shoulder rests a zinc tube, which reaches rather more than half way up the pendulum rod. To the top of this tube is fastened another shoulder, and to this second shoulder is fixed an outside steel tube inclosing the zinc one. To this outside steel tube the bob (of lead) is fastened at the centre of the bob. The outside steel tube is cut away, and the inside zinc one bored with holes, in order to let in changes of temperature to the central steel rod. In action this pendulum is very similar to the gridiron, but the expansion of zinc being much greater than brass, much less of it is needed.

It is important that the bob should be fastened at its centre, because owing to its bulk it would be sure to lag behind, and this can only be got over by neutralising its expansion as far as possible.

The compensation action necessary for watches and chronometers is far greater than that required for clocks; for, whereas a clock, with a simple iron-rod pendulum, will lose three seconds a day for every

ten degrees Fahrenheit of rise in the temperature; a watch or chronometer with a plain uncompensated balance will lose one minute a day for the same difference.

The cause of this is, that in the case of a watch or chronometer, a change of temperature, in addition to increasing or diminishing the diameter of the balance-wheel, produces a very great alteration in the elasticity of the balance-spring. The error arising from this latter cause is at least five times as great as the error arising from alteration in the diameter of the balance.

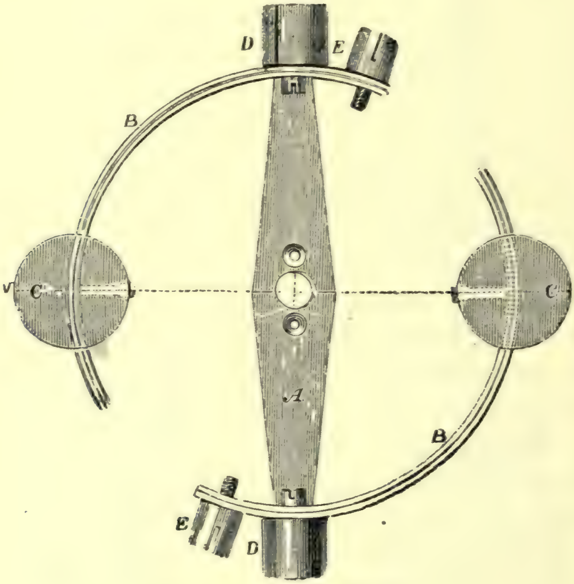


FIG 257.—Compensated balance.

The method of compensation employed is the following. The rims B B of the balance wheel (see Fig. 257) are composed of laminæ of brass and steel fastened together, the brass being upon the outside of the rim, and the steel upon the inside. With any increase of temperature, the brass endeavours to expand faster than the steel, but as it is rigidly, throughout its entire length, fastened to the steel (having in fact been melted on to it) it cannot well do this: the only way it can manage matters is by bending in the rim a little; it does this by increasing the length of the outside of the rim, as compared with the inside.

By this means the weight is carried a little way in towards the axis of motion, which reduces the time of the swing of the balance, at a sufficient rate, to compensate for its slower motion, due to the loss of elasticity of the balance-spring. The reverse action takes place with any fall in temperature.

The effect of the compensation may be altered by sliding the weights CC towards or away from the ends of the rims.

The action of this balance, although sufficiently accurate for ordinary purposes, still leaves a small error at wide ranges of temperature. For instance, supposing that you so arranged the position of the weights upon the rims that the chronometer should go right at a temperature of thirty-two degrees and sixty-six degrees; if you raised the temperature to one hundred degrees, you would find that your chronometer would lose four seconds a day; and you could not alter this error by sliding the weights further along the rims to increase their action in the heat; because by doing so, you would increase their action in the cold; and then the chronometer would lose in that direction. The best that you could do, would be to divide the error and leave the chronometer losing two seconds a day in the heat, and two seconds a day in the cold.

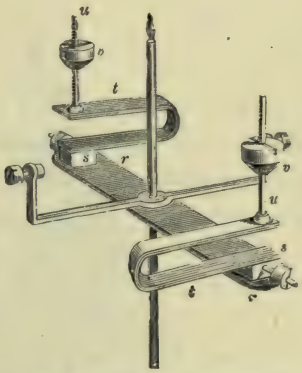


FIG. 258.—Dent's compensation balance.

The cause of this error—this secondary error, as it is called—is that the time of the swing of the balance varies, not as the distance of its weights from its centre, but as the square of that distance. Consequently it requires a greater motion of the weights inwards than outwards to produce the same difference of time. The late Mr. Dent, who was the first to point out the cause of this error, designed the following arrangement (Fig. 258) for correcting it:—

r r is a flat compensation bar, formed of brass melted on to steel, the steel being uppermost. The two loops or staples, *s*, *t*, *s*, *t*, fastened at each extremity are also compensation pieces, the brass being upon the inside. The compensation weights, *v v*, are mounted upon upright rods at the extremities of these loops. When there is any increase of temperature the main bar, *r r*, bends upwards, and tilts in the staples

and the rods at their ends. But the staples, being compensation pieces themselves, open in the heat, and advance the weights a little further in upon their own account: they assist the main compensation in the heat. In the cold, however, they reduce it; the main bar, *r r*, bending downwards tilts out the weights, but in this case the staples close a little, and bring back the weights a small portion of the way again. Thus you get increased action in the heat, and reduced in the cold, which compensates for the secondary error. The effect of the main compensation is altered by raising or depressing the weights upon the rods, as they then work at the extremities of longer or shorter levers.

§ III.—Distillation.

There are two phases in the operation to which the name of distillation has been given—an operation which is intended to separate a liquid from solid matters in solution in it, or from another liquid with which it is mixed.

The first phase consists in reducing the liquid to a state of vapour by boiling. If it contains foreign substances in solution, such as salts, as is the case with most ordinary waters from springs, or rivers, or the sea, the watery part alone is vaporized—the foreign substances remaining at the bottom of the vessel—and their separation is thus effected. If the mixture is with a liquid of another kind, boiling will still separate them, at all events partially, provided the boiling points of the different liquids is not the same, because one of the liquids will rise in vapour before the other.

Since the end proposed in both cases is to obtain in more or less purity the liquid in question, it must be made to change its state again after having been reduced to vapour, and to return to its primitive condition. This is the object of the second phase of distillation, and it is easily accomplished by cooling and condensing the vapour.

Distillation is a long known industrial operation, and used to be carried on by means of an apparatus known as an alembic, Fig. 259.

This consists of a boiler *a*, called the cucurbit, surmounted by a retort, *b c*, called the head. When placed on the fire and filled with the water to be distilled, it communicates at *d* with the part of the

apparatus called the coil, because it is twisted in a helix. The vapour produced by boiling rising above the water in the cucurbit, is carried to the coil and there condenses by contact with the sides, which are kept constantly cool by a vessel of water in which the coil is plunged. The distilled water is collected outside this vessel in a bottle, *g*. The constant condensation of the vapour can only take place by the exchange of the heat of vaporization with the water in the vessel *e*, and its consequent elevation of temperature. The cold water must therefore be renewed as fast as the distillation is effected, and this is done by means of a tap *K*, which brings the cold water to the bottom of the vessel through the funnel *h* and tube *d*, while the warm water runs away from the top by the pipe *i*.

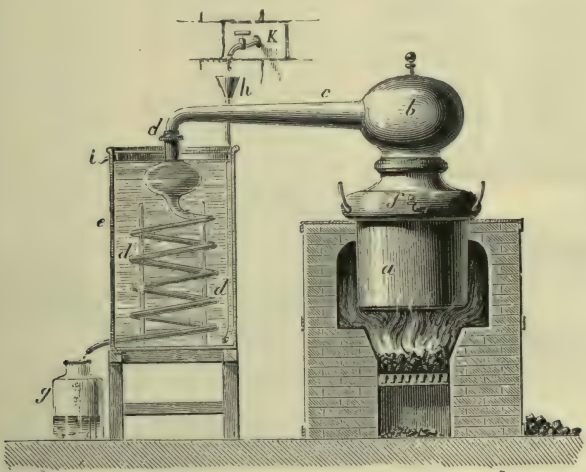


FIG. 259.—The alembic, a distilling apparatus.

The alembic is employed on shipboard for distilling sea water, and is able to a certain degree to supply fresh water for the requirements of the crew. Water distilled in this way is worth about a halfpenny a gallon.

A distilling apparatus is more complicated when we have to deal with a mixture of liquids unequally volatile, such as alcoholic liquids. With an ordinary alembic indeed, and several successive distillations, we can obtain the concentrated liquid sought for to a certain degree of purity, but in this case the liquid, as alcohol for example, always has a burnt flavour, and this must be destroyed.

This result is accomplished by an apparatus such as that of which Fig. 260 represents the appearance, and which we will succinctly describe.

A is the boiler directly heated by the fire. B is another boiler heated by the gases of combustion whose heat is thus utilized. Two refrigerators, R, R′, contain coils in which the condensation of the vapour of the distilled liquid takes place. Every part of the apparatus, both boilers and refrigerators is filled with the liquid, say wine. It is introduced first into the refrigerator R′ and it runs by an overflow pipe

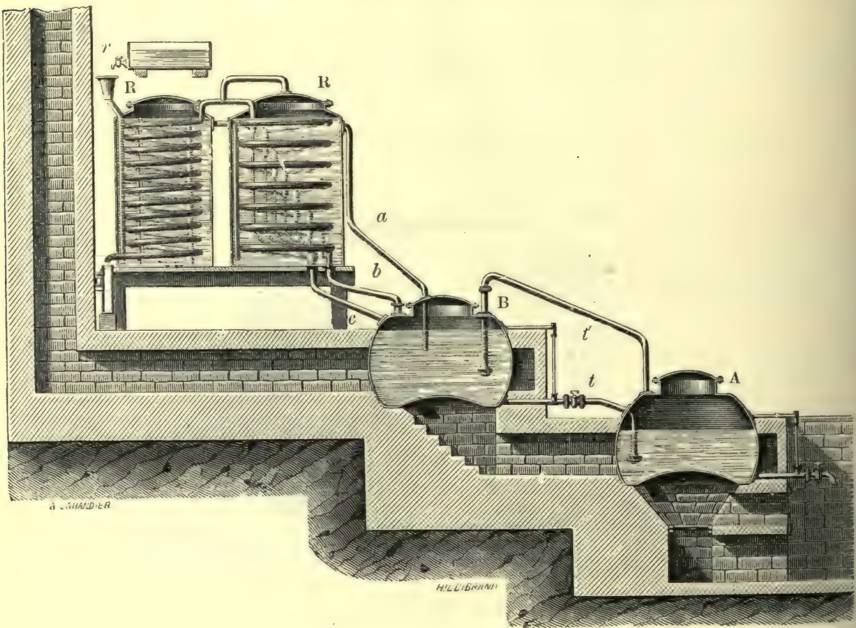


FIG. 260.—Laugier's apparatus for the distillation of alcohol.

into R, thence by the pipe *a* into the boiler B and by the pipe *t* into the boiler A. The vapour follows a precisely opposite course. From A it passes by *t′* into the boiler B; from here by *b*, it passes to R, where it partly condenses in a series of partial coils. The condensed liquid returns to B by the pipe *c* common to all the coils; and the portion of the vapour which remains uncondensed passes on to the coil R and is there condensed in its turn.

It is set in action in the following way. When the liquid has risen in B to the level of the rose, the pouring in is stopped, the boiler

A is three parts filled, and the heating is commenced. Then while the alcoholic portion is condensed in the coil in B′, the more aqueous portion returns to B, raising its level, while that of A is lowered. When the latter is only a quarter full, the residue is emptied by the discharging tap. The tap *t* is then opened, and A fills itself at the expense of B; after which more is poured in at *r*, without stopping until B, which receives liquid from three sources, is again filled and A is reduced to its former state. All then commences again, and the operation is continued indefinitely.

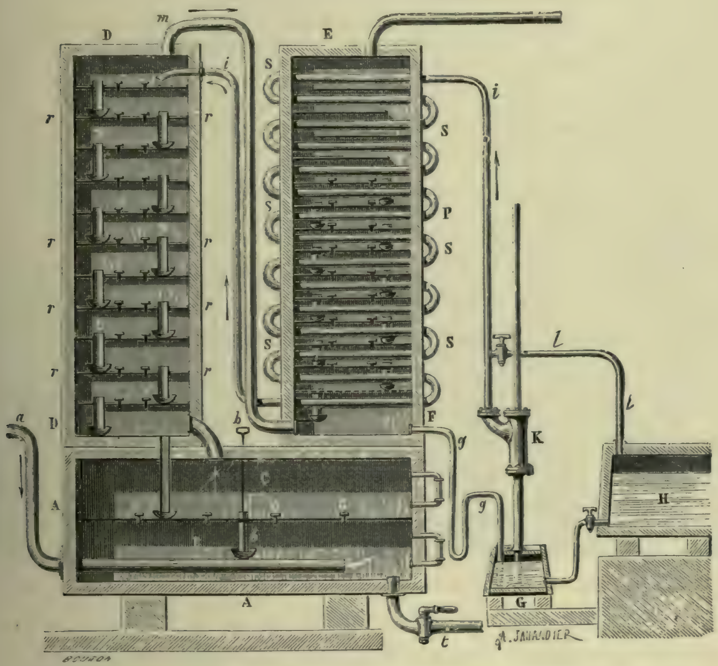


FIG. 261.—Coffey's apparatus for the distillation of alcohol.

The distillation of wine, and of all the fermented liquors obtained from cereals, as wheat, rye, barley, maize, potatoes, beetroot, &c., is widely spread in all European and American countries. It is the final operation of a considerable industry, that of the preparation of alcohol. The distilling apparatus are very various. In France, besides Laugier's apparatus just described there are Cail's and Champonnois's; in Germany, Dorn's, Pistorius's, and Gall's; in England

Coffey's,[1] represented in Fig. 261. We may refer to Wurtz's *Dictionary of Chemistry* for a description of these, as it is sufficient here just to indicate their physical principle.

§ IV.—Evaporation of Salt Waters.—Water-coolers.—Manufacture of Ice in Bengal.

A great part of the salt (sodium chloride) we require comes from sea-water, of which it forms about $\frac{1}{44}$ or $\frac{1}{37}$ part. By evaporation in the open air in large shallow basins, the sea water is concentrated by degrees, and the salt is deposited on the bottom of the basins in the form of crystals, and on the surface of the water in a thin solid crust. The evaporation is hastened by the rise of temperature due to the sun's rays, and by the wind. It is therefore in the hot season that the salt is collected in the brine pits, and the series of very simple manipulations carried out that constitute this industry. The salt is piled up in heaps which are left exposed to the air for a certain length of time to allow of the diliquescent substances which may be mixed with it to dissolve ; the salt thus drained is afterwards sent into the market.

Salt is also obtained by the evaporation of the water of salt springs, but as these contain ordinarily only a small proportion of salt, they have first to be concentrated by being submitted to a prior evaporation in the open air, after which the process is completed by submitting the concentrated waters to the action of heat. The salt is deposited in the boilers by which this second operation is carried on.

The evaporation of salt waters in the open air is accomplished in the following manner. Heaps of faggots are piled up and supported by a frame-work fixed over the basin in which the water is received (Fig. 263), this water escapes by a series of flow pipes *a,a.* . . , from the troughs AB, CD, situated on the upper part of the frame-work, to which is given the name of graduation pile (*bâtiment de graduation*),

[1] "To give an idea of the dimensions of Coffey's apparatus, we need only mention that Messrs. Currie, of Bow, obtain annually more than 4,675,000 litres of alcohol, 65 degrees above proof, from the distillation of the fermented must of barley and oats, with the addition of malt. This single house pays a duty of £400,000 per annum."—*Dictionary of Chemistry*, Art. "Alcohol."

and which is fixed so that its longest side may be in a direction perpendicular to that of the prevailing wind. The water thus trickles down over the branches and little twigs of the fagots so that it presents a large surface to the air; evaporation is then very rapidly effected, and the water in the basin becomes much more concentrated than that of the supplies. It is drawn up again a second or a third time by the pumps P, P′, until a sufficient degree of concentration is effected and the evaporation is completed in the boilers.

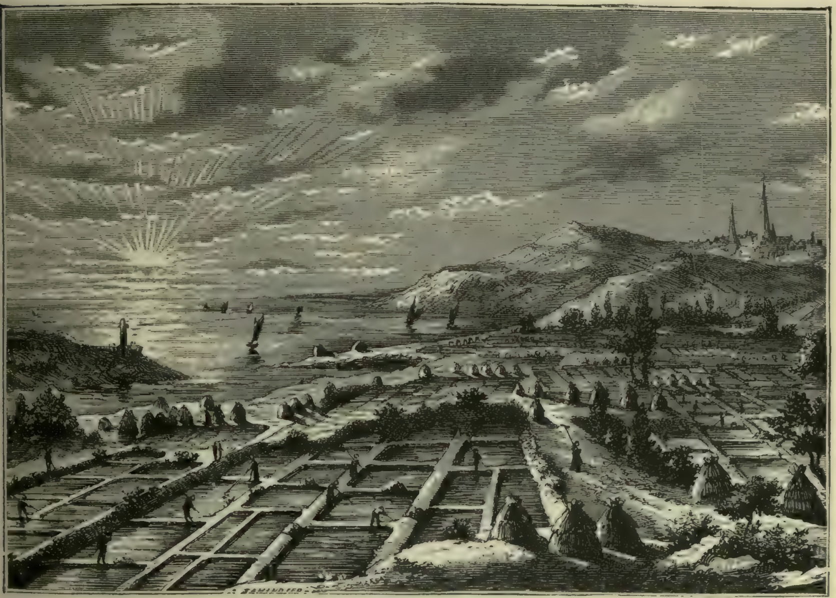


FIG. 262.—Salt pits in the west of France.

The porous vessels to which the name of water-coolers[1] is given, and which serve to keep the water cool in summer, are known to all. The property which this kind of bottle possesses is due to the cold resulting from the evaporation of the water from the outer surface. The water which soaks through the sides, and evaporates all the faster when the air is warm and less saturated with vapour, is constantly replaced from the water within. The decrease of temperature resulting from this evaporation prevents the water in the

[1] Called in Spain *alcarraza,* a word derived from the Arabic *al quraz,* a jug.

bottle getting hot, as would be the case if the sides of the vessel were impermeable.

It is this evaporation, so abundant and so rapid on clear nights, which gives rise to the formation of dew, which is a condensation of the vapour in the air in little drops on the surface of exposed objects. When the resulting cold is sufficiently intense the drops freeze and produce hoar-frost. In Bengal, where the temperature is too high for ice ever to form naturally, it is obtained artificially in the following

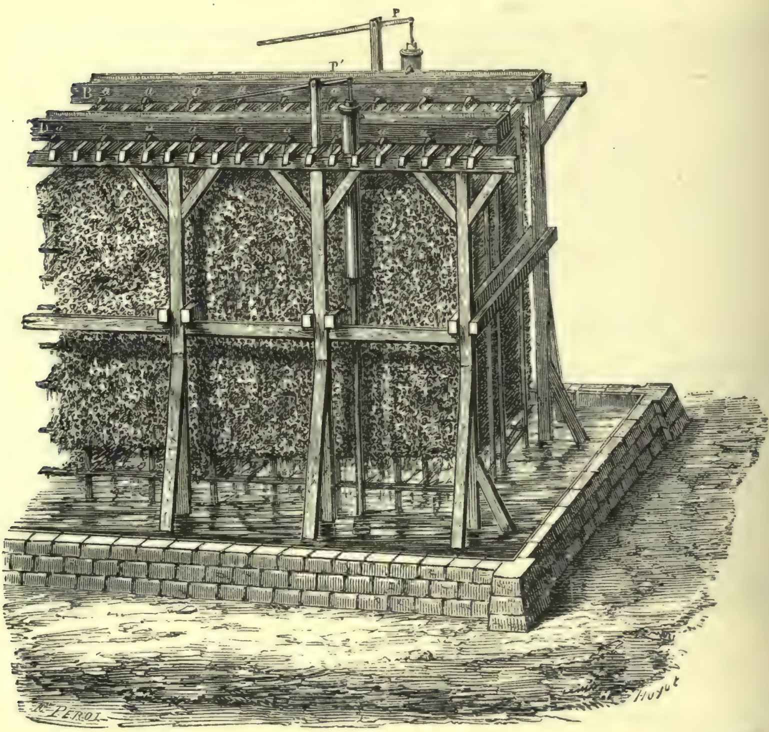


FIG. 263.—Graduation pile for the evaporation of salt waters.

manner. Tyndall explains in these terms[1] the process employed, and the cause of the physical phenomenon of which it is an application :—

"Wells (the author of *The Theory of Dew*) was the first," he says, "to explain the formation artificially of ice in Bengal, where the substance is never formed naturally. Shallow pits are dug which are partially filled with straw, and on the straw flat pans containing

[1] *Heat as a Mode of Motion*, p. 461.

water are exposed to the clear firmament. The water is a powerful radiant, and sends off its heat copiously into space. The heat thus lost cannot be supplied from the earth, this source being cut off by the non-conducting straw. Before sunrise a cake of ice is formed in each vessel. This is the explanation of Wells, and it is, no doubt, the true one. I think, however, it needs supplementing. It appears from the descriptions, that the conditions most suitable for the formation of ice is not only a clear air—but a dry air. The nights, says Sir Robert Baker, most favourable for the production of ice are those which are clearest and most serene, and *in which very little dew appears after midnight.* The italicized phrase is very significant. To produce the ice in abundance the atmosphere must not only be clear, but it must be comparatively free from aqueous vapour. When the straw on which the pans were laid became wet, it was always changed for dry straw; and the reason Wells assigned for this was, that the straw, by being wetted, was rendered more compact and efficient as a conductor. This may have been the case, but it is also certain that the vapour rising from the wet straw and overspreading the pans like a screen would check the chill and retard the congelation."

§ V. Artificial Manufacture of Ice.

Ice is very largely used in these days in all civilised countries, as it serves not only for cooling all sorts of drinks in summer—for making ices, creams, &c.—but is used also in medicine and surgery in the treatment of certain diseases and in dressing wounds. Its consumption in Europe and America is considerable. It is obtained in blocks from Russia, Sweden, and Norway, and from the surface of the lakes in Canada, whence it is carried by sea to the southern countries. To transport these blocks without exposing them to melting by the milder temperature of their destinations, they are arranged in layers in boxes, which are surrounded and separated by sawdust. The slight conductivity of this material is sufficient to protect the ice during the voyage. On its arrival it is kept in ice-houses, from which it is taken when required.

But it has been attempted to make it on the spot, and at the moment it is wanted. The apparatus invented for this purpose are

founded on the same principle as that we have explained already, namely, the cold produced by rapid evaporation.

A cylindrical boiler, partly filled with a solution of ammonia, is placed on a furnace till a temperature of 130° C. is attained, which is ascertained by a thermometer whose stem passes through the cover. The ammoniacal gas is disengaged, and passes by a conducting tube into a refrigerator or vessel in the form of an inverted truncated cone, plunged in a tub of cold water. In the inside of this refrigerator is placed a cylindrical vessel containing the water to be frozen, and this is the way in which the result is obtained. The ammoniacal vapours which are incessantly disengaged from the boiler are cooled by the water in the tub, and are in addition submitted to an increasing

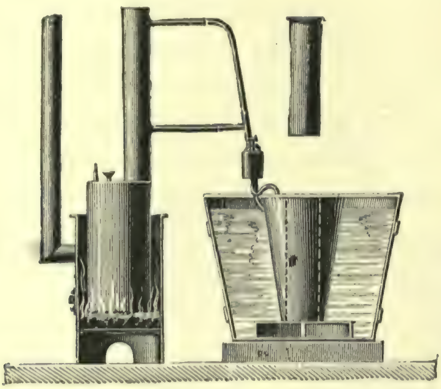


FIG. 264.—Carré's apparatus for the artificial manufacture of ice.

pressure, they condense, the gas liquefies and remains inclosed in cups fitted to the sides in the annular space surrounding the central cylinder. The furnace is now replaced by a tub of cold water—the water in the boiler, on cooling, becomes able again to dissolve the ammoniacal gas, which rapidly returns to its gaseous state. This evaporation necessitates an absorption of heat which takes place at the expense of the central vessel and of the water which it contains, a block of ice can then be soon taken out of it.

The apparatus just described, which is represented in Fig. 264, is for domestic use, as the quantity of ice it can produce is small. The larger apparatus constructed by the same inventor for the commercial manufacture of ice is arranged differently.

A is the boiler where the solution of ammonia is heated. The gas which escapes from it is carried to the receiver, B, where it liquefies by cooling. C is a reservoir out of which a jet of cold water constantly runs to renew the water in the receiver. The liquefied gas passes on to fill the hollowed sides of the refrigerator, G, where vessels filled with the water to be frozen are placed. The water of the boiler, deprived of its dissolved gas and cooled, then passes into a vessel, E, which is in communication with D, and with the refrigerator. The liquid ammonia resumes the gaseous state, to dissolve again in the water in the vessel E, and it is by the cold caused by this evaporation that the water freezes in the vessels

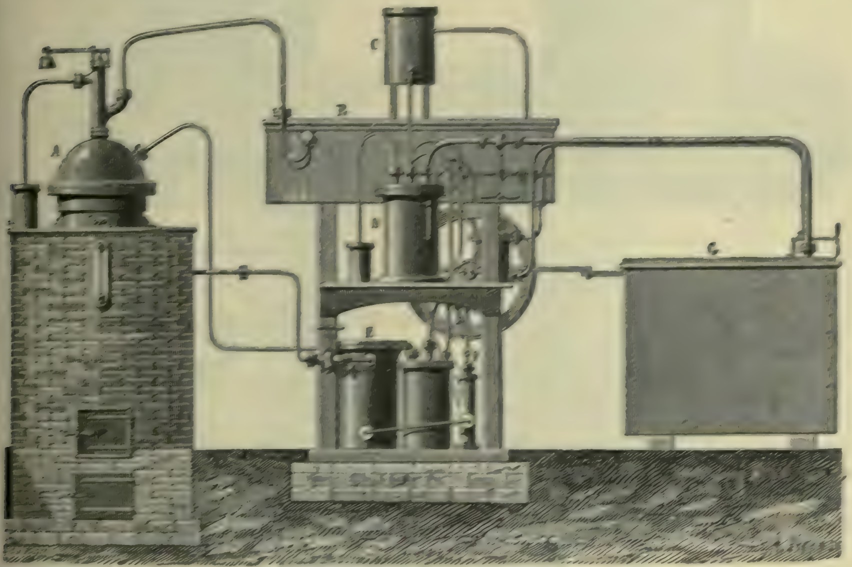


FIG. [illegible].—Carré's large apparatus for the artificial manufacture of ice.

placed within the refrigerator. The water restored to its original state again, is raised by a pump, F, to the boiler, so that the manufacture of ice goes on in an almost continuous manner.

We next give some further details on the artificial production of ice based on the cold that results, not only from the brisk evaporation of a liquid, but from the solution of certain substances. The cause is still a change of state, but here it is a liquefication of a peculiar kind, requiring molecular work, and, in consequence, absorbing a

more or less considerable quantity of heat. The set of substances thus mixed to produce cold is called a *freezing mixture.* The

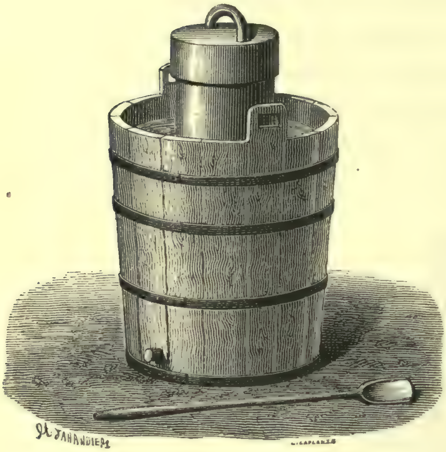


Fig. 266.—Ice-pail.

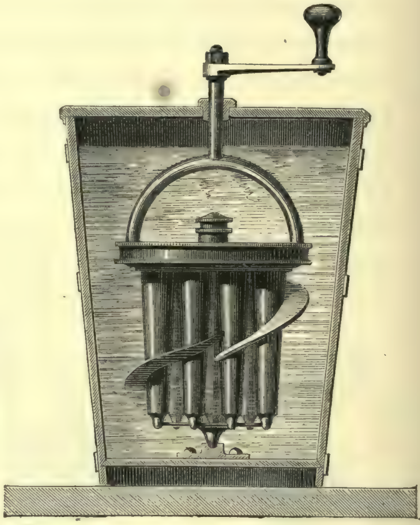


Fig. 267.—Goubaud's ice-machine.

following are some of the freezing mixtures most commonly employed:—

Two parts of snow or pounded ice with *one* part of salt produce a

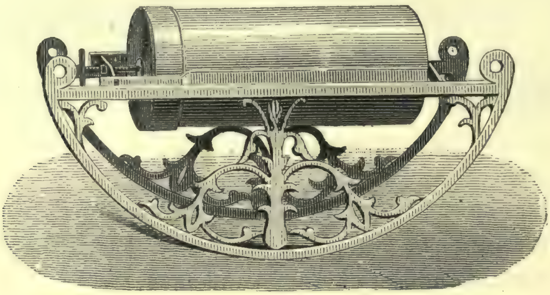


Fig. 268.—Rocking ice-machine.

cold which may reach 21° C. below zero. Five of ammonia chlorohydrate, five of porassic nitrate, eight of sodium sulphate, and sixteen of water, produce a cold of 15°.

One part of ammonia nitrate and one of water give a maximum effect of 15°.

Lastly, three of snow and four of hydrated calcium chloride give a cold of 48°.

The following are some of the apparatus based upon this action :— A mixture of pounded ice and salt contained in a pail into which is introduced a vessel with the syrup, juice, or cream to be frozen, or, according to the usual expression, to be turned into ices, is one of the simplest of these machines—It is called the ice-pail (Fig. 266).

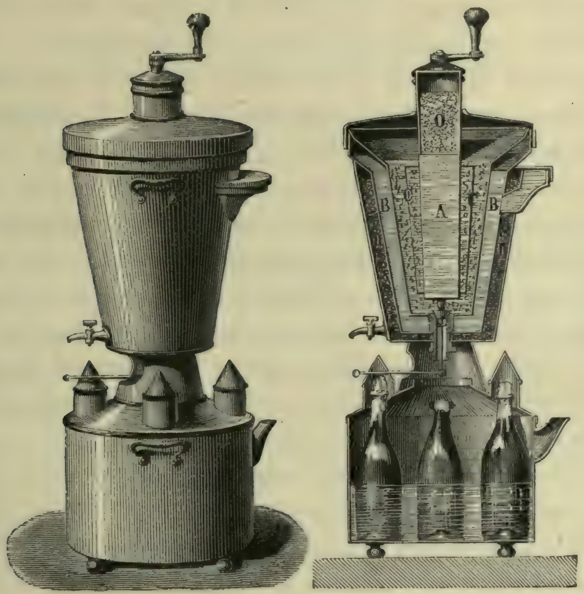


FIG. 269.—Family ice-machine.

Figures 267, 268, and 269 represent ice-machines for family use, all constructed and based on the principle that the cold produced by solution, which is made available, either by the movement of a rocker, or by a rotatory movement impressed on the refrigerating liquid by means of a handle and plates arranged in a helix surrounding the vessel containing the water or syrup to be frozen. In the family ice-machine the melting water from the ice drips through the bottom and sprinkles the bottles of wine, which are thus cooled, or as the gourmands say, *iced.*

The most recently invented process of ice-making is that devised by M. Pictet, who utilizes sulphurous acid. The following is a description of a machine which can produce 250 kilogrammes of ice per hour :—

A cylindrical tubular copper boiler has a length of 2 metres and a diameter of 35 centimetres ; 150 tubes of 15 millimetres traverse its entire length, and are soldered by their extremities to the two ends. This first boiler is the refrigerator. It is placed horizontally in a large sheet iron vat, which contains 100 tanks of 20 litres each. An incongealable liquid, salted water, is constantly circulating in the interior of the refrigerator by means of a helix. This liquid is re-cooled to about $-7°$ in a normal course, and it is in contact on its return with the sides of the tanks which contain the water to be frozen.

In the space reserved between the tubes of the refrigerator, the sulphurous acid liquid is volatilised, its vapours are drawn up by an aspirating force-pump, which compresses them without the condenser. This condenser is a tubular boiler, the same as the refrigerator ; only a current of ordinary water passes constantly into the interior of the tubes to carry off the heat produced by the change of the gaseous into the liquid state of the sulphurous acid, and by the work of compression. A tube furnished with a gauge tap, adjusted by the hand once for all, permits the liquefied sulphurous acid to return into the refrigerator to be subjected anew to volatilisation.

The work necessary to manufacture 250 killogrammes of ice per hour is at the most seven-horse power.

A cold of 7° in the bath is amply sufficient to obtain in the tanks a rapid and in every way economical congelation.

With these mechanical arrangements the following important advantages are realised :—1. The pressure never exceeds four atmospheres. 2. There is never any entry of air to fear, the pressures, as far as $-10°$ C., being always above that of the atmosphere. 3. The volatile liquid employed is perfectly stable, undecomposable, and without chemical action on metals. 4. All greasing in the machine is dispensed with. 5. The volatile liquid is obtained at a very low price, and it is accompained by no danger of explosion or fire. 6. The cost of production of the ice approaches very near to the theoretic minimum; it is about 10 francs per ton of ice.

CHAPTER V.

THE STEAM-ENGINE.

§ I. THE MOTIVE POWER OF STEAM.

THE ancients were acquainted with the elastic force of steam, and without having any very clear or precise notions of its physical properties, they endeavoured to avail themselves of it.

For this purpose Hero of Alexandria invented the machine to which he gave the name of *eolipylé*, as well as other apparatus in which the action of compressed or rarefied air was called into play. We shall see, in fact, that the movement of the *eolipyle* was simply caused by the expansive force of the steam, though working in an entirely different manner from that of a modern steam-engine.

It consisted of a pot or boiler, partly filled with water, placed on the fire, and closed by a lid. Over this was fixed a hollow bent tube, with a tap, which supported and communicated with the inside of a hollow metallic sphere, which was also supported at the opposite extremity of the diameter by another tube not communicating with the inside. The sphere was movable about this axis of support. Two other hollow bent tubes projected from the surface of the sphere in a direction perpendicular to the axis of rotation. With this explanation we can easily understand the motive power of the steam in this little apparatus. The tap is opened, the steam rushes from the boiler to the tube and fills the sphere. If this were entirely closed, it would remain motionless, but the steam which exerts the same pressure on all points of the inner surface of the sphere, finding two openings, escapes with a noise as it condenses in the air; the reaction which would produce equilibrium if the sphere were entirely closed, exerts a force in the contrary direction; and the sphere revolves

with greater or less rapidity in the opposite direction from that in which the steam issues.

The eolipyle (which signifies an eolian or air opening) is, as we have seen, a machine where the elastic force of the steam works by its reaction. It has never been more than an amusing physical toy, in spite of its having attracted the attention of savants and of experimentalists before the time of Papin, and of a proposal being made to utilize it for turning jacks.

Some thirty years ago, however, Sir Arthur Cotton succeeded in driving the fan for the air-blast of an iron-founder's furnace by means of one of these engines, and has during the present year (1876) been

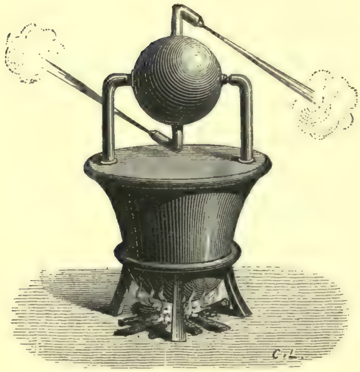


FIG. 270.—The eolipyle of Hero of Alexandria.

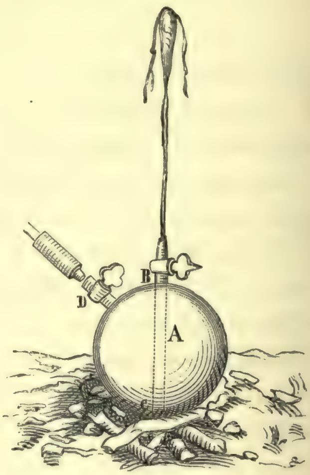


FIG. 271.—Solomon de Caus's apparatus.

making further experiments with a view of applying the principle to useful purposes.

The apparatus described by Solomon Caus in his pamphlet, *Les Raisons des Forces Mouvantes* (1605), is a more direct example of the application of the expansive force of steam. Water is introduced by the tap, D, into the hollow sphere, A, which is placed on the fire after closing the tap. A tube, BC, passes by another opening, B, into the water, without touching the bottom. When the steam has been generated in a sufficiently large quantity, and its tension is great enough, the tap of B is opened, and the water, pressed upon at its upper surface by the elastic force of the steam, is forced out of the tube.

A complete and detailed account of all such endeavours, and of the rough mechanical means by which it has been attempted to utilise the various forces of nature—such as that of compressed and rarefied air and of steam—has an interest of its own in regard to the history of the progress of the application of human knowledge. But all this would only be seriously instructive at the time when physics, escaping from the period of subtle and unsuggestive explanations, was entering upon that of experiment under the impulse of Galileo, Boyle, and Huygens. The steam-engine could only have been invented, or have received those improvements which make it a really practical motive power, in an age that had seen the di covery of the properties of air, the barometer and thermometer. Papin and Watt are the offspring of Torricelli and Galileo. The steam-engine is the child of two simple and fertile inventions; that of the *barometer*, which proves and measures the atmospheric pressure, and compares it with the elastic force of gases and vapours; and that of the *thermometer*, which measures the degrees of heat. The means of producing a vacuum, whether in the barometric tube, or in a receiver from which the air is exhausted by a pump—the valuable invention of Otto von Guericke—had also been discovered when Denis Papin, of whom France may well be proud, laid the foundations of the greatest industrial revolution the world has ever seen.

But that we may follow accurately the train of ideas which passed in the minds of those great men whose names are associated with the invention of the steam-engine, it is indispensable to enter into some preliminary details.

§ II. Papin.—First Attempts.

As early as 1680 Huygens had proposed to utilize the expansive force of gunpowder in the following manner. In a cylinder provided with a movable piston he caused a certain quantity of powder to be exploded, and the violent expansion of the gas drove the air contained in the cylinder out of two openings so arranged that they closed again immediately. A vacuum was thus made, or at least a partial one (on the cooling and consequent loss of pressure of the gas contained in the cylinder), so that the atmospheric pressure acted on the

upper face of the piston with a force proportional to the surface, and having a definite relation to the degree of exhaustion obtained.

A humble French physicist, Denis Papin, whom the revocation of the Edict of Nantes forced into exile, afterwards[1] tried to improve upon the machine proposed by Huygens; a machine which, moreover, in the opinion of its inventor, "could be used not only to raise all kinds of heavy weights, and water for fountains, but also project bullets and arrows with considerable force, like the balista of the ancients." But shortly after, in 1690, he proposed to substitute for gunpowder another agent, which, like it, could produce a vacuum beneath the piston, and leave it exposed in this way to the whole pressure of the atmosphere.

This agent was steam, with which Papin was already familiar, since in 1681 he had invented his celebrated boiler, or *new digester*, of which we shall speak hereafter. We now give briefly a description of the first steam-engine as it was conceived by Papin, and the explanation of its effects which is easily intelligible.

In Fig. 272 B is a piston provided with a vertical rod, D, and movable in a cylinder of the same diameter, into the inside of which is introduced a little water. In the piston is bored a hole which can be closed at pleasure by the rod M.

Let us suppose the piston placed in the cylinder just in contact with the water (which has passed through the opening, which is then closed by means of the rod). Let us now place the cylinder, which is made of metal, upon a hot fire. The water is soon reduced to steam, and this, by its elastic force, overcomes the weight of the piston and the pressure of the atmosphere, and drives the piston to the top of the cylinder; when the piston arrives at the end of its stroke, a narrow rod, C, movable about one of its ends, and until now kept in contact with the piston-rod by the spring, G, enters an opening in the rod, as soon as that opening is brought opposite its extremity by the ascent of the piston. At this moment then the motion is stopped. We now take away the fire from beneath the cylinder, and it and the water contained in it becomes cool, the vapour condenses, and a vacuum is produced below the piston, so that if the rod be taken out of the opening in it, it will be pressed down by the weight of the

[1] The first attempt dates from the year 1688.

atmosphere, and advantage may be taken of this considerable pressure to enable it to raise weights.

In one word, the arrangement of Papin's machine is slightly different from that in which Huygens made a vacuum by gunpowder, but the effect produced is the same. Only it is steam that works it, and its elastic force raises the piston, and its condensation by cold makes the vacuum.

Let us insist here upon two facts—Papin in this original steam-engine, employed at first the elastic fluid at a pressure a little greater than that of the atmosphere; he then made use of it as a motive power to raise the piston, afterwards he condensed it by cooling so as to make a vacuum, and then the atmospheric pressure becomes the true motive power, and accomplishes the work for which the machine is constructed. Later he modified his first conception, but not happily, as we must confess, and it is the engine just described that constitutes his great title to honour, and his incontestable right to be considered as the inventor of the steam-engine.

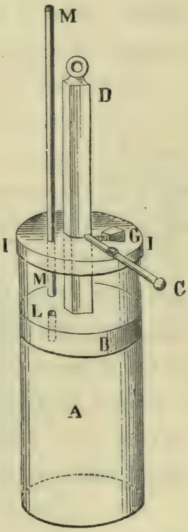


FIG. 272.- Papin's first steam-engine.

Papin first proposed to use his engine as a pump; for this purpose the water was admitted by a suitable valve below the piston, steam was then admitted above, and by its expansive force drove the water up and out by the out-flow pipe. His engine differed from the one subsequently suggested by Savery mainly in the employment of the piston, while the latter allowed the steam to come in contact with the water, thus losing a great deal of power by condensation. Papin later intended to employ his engine as a prime mover by causing the water issuing from the cylinder to work a water-wheel.

Both Savery and Papin got as far as producing the steam in one vessel and using it in another, but it remained for Watt to make the next most fundamental improvement, viz., that of condensing in a separate vessel, as well as separating the steam cylinder from the pump-barrel.

Although Savery conceived the happy idea of producing the steam in one vessel and condensing it in another; yet his engine

is in every other respect a step backwards from Papin's. In fact, the elastic force of the steam was employed in it to drive back the water directly, while Papin used it to produce motion in the piston—a movement which it is only necessary to transform by purely mechanical processes to render the engine a universal prime mover.

We will briefly describe the principle of the modern steam-engine, and the principal parts of which it is composed.

First, and above all, a means must be devised to develop the force, that is to say, to produce and collect a certain quantity of steam. This is accomplished by heating a boiler filled, or partly filled, with water. This is the *steam generator*, one of the three essential parts or constituents of the engine.

From the boiler the steam passes into a chamber of cylindrical form, divided into two parts by a movable piston; it is here that, by special arrangements, the steam acts first on one side and then on the other of the piston, so as to give it an alternate to and fro motion, which is the direct object of the machine.

This form is called a double-acting engine. All the earlier and many even of the most efficient engines of the present day, the "Cornish engines," for example, are single-acting; that is to say, the steam is employed only to drive the piston one way, it is then allowed to escape into another vessel purposely kept cool, where it condenses, leaving the unbalanced pressure of the atmosphere to drive the piston back again.

The cylinder, the piston, and accessories, which distribute the steam in the two chambers of the cylinder, constitute that part of the engine called the prime mover. It is the engine, properly so-called, the action of which would not be well understood without entering into further details.

Consider Fig. 273, which represents the steam-engine reduced to its essential parts. C is the boiler where the water is converted into steam, which fills its upper part as well as the pipe VV. This pipe conducts the elastic vapour into a chamber *b* next to the cylinder, called the *valve chest.* Two taps R'R' admit the steam, according as one or the other is open into the upper chamber B or the lower chamber A of the cylinder. First suppose the upper tap open and the lower closed. The steam passes into B, where it presses upon the piston, and tends to impress upon it a descending motion in

the cylinder; when the upper tap is closed and the other opened, the steam will pass into A, where it will work on the lower surface of the piston and tend to make it rise.

But here a difficulty presents itself—if the steam is present at the same time in A and B, since its elastic force is the same on both sides, its action on the lower face will exactly compensate its action on the upper face and no motion will be produced.

Some means then must be found to destroy its elastic force as soon as it has acted, and this alternately in the two chambers of the cylinder. This is accomplished by opening successively the taps R',R'; by which the steam is permitted, after forcing the piston to the opposite end of the cylinder, to escape freely into the open air, or to pass into a vessel which contains cold water, the sides of the chamber being also kept at a low temperature. As soon as the steam reaches this chamber, which is called the *condenser*, it is almost entirely precipitated in the form of liquid, and what remains is at a very low *pressure*, far inferior to that of the steam either in the boiler or the cylinder.

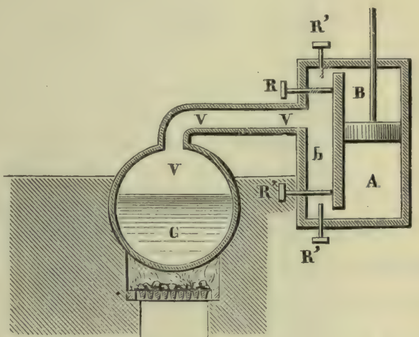


FIG. 273.—The essential parts of the steam-engine.

This arrangement is necessary in engines in which the steam acts with a tension not much greater than that of the atmosphere; when the tension of the steam is equal to several atmospheres, a condenser is no longer required, the condensation may take place in the open air.

It is easy to see then that in either of these cases the difficulty is overcome; for if we imagine the upper tap R open and the lower one closed while the upper tap R' is closed and the lower one opened, the steam enters B where it exerts its force, while that which is in A condenses, and a vacuum is formed below the piston which descends to the bottom of the cylinder. At this moment the taps are reversed; the steam in the boiler enters A, that in B condenses, and the piston is lifted from the bottom to the top. And so on indefinitely.

This then in its principle and fundamental arrangements is the

modern steam-engine. An alternate rectilinear motion is obtained by the action of the elastic force of steam in a completely closed cylinder; which action ceases immediately that the steam is condensed by cooling. The motion being obtained, all that is required more is to apply it to a useful purpose by transforming in a thousand ways, according to the requirements of the manufacturer, or the use to which it is to be put; whether, for example, it is required for great power or great speed, or speed and power combined. The machinery which carries out this transformation is a third element which we must study in order to complete the description of the steam-engine, which thus includes—

The steam generator or boiler.

The driving and distributing machinery or prime mover.

The machinery for transmission.

We will now study in detail each of these parts of the engine.

§ III.—The Boiler, or Steam Generator.

The forms of boilers now adopted are so numerous that we cannot attempt even to enumerate them all; it will be amply sufficient for present purposes to explain in what the principal systems resemble each other and in what they differ. But before pointing out this we must describe rather more particularly an example of one of them. We will take the boiler most commonly adopted in manufactories where stationary engines are employed, that is, engines erected and fixed in the place where they are to work. Fig. 274 gives an exterior view of one. We will explain the interior arrangements.

On the upper part of the brickwork rests a large wrought-iron vessel of a cylindrical form throughout its whole length, and having a hemispherical termination at either end. This is the body of the boiler, the chamber which contains the greater part of the water to be vaporized. Figs. 275 and 276—the one a transverse section, the other a longitudinal one—show it at C.

Below the principal body are two, sometimes three, long cylindrical tubes B B, which communicate with it by short tubes.

These *heaters*, completely filled with water, are directly exposed to the furnace, whose flames play upon their outer surface, and it is

obviously in these that the greater part of the heating takes place, and hence they are appropriately called heaters.

The two figures indicate with sufficient clearness the positions and dimensions of the furnace, the grate and the ashpit, on which no more need be said.

With regard to the chimney, its base is seen at U, and we can follow the course of the smoke and the gases of combustion, from their

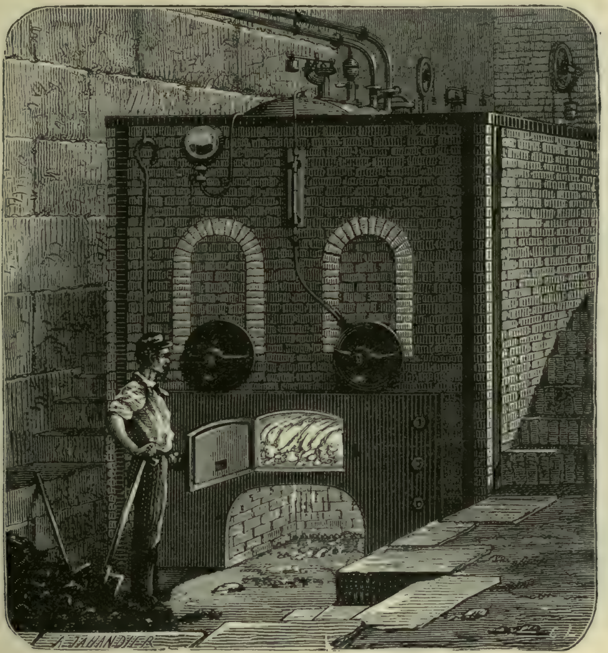


FIG. 274.—Boiler, with heaters (exterior view).

origin in the fire to the chimney bottom, through flues C C, which pass between the heaters and the boiler.

The position of these flues must be taken note of. The one below the heaters causes the flame and the heated gases to pass to the end of the furnace and heat the heaters themselves directly. From thence the gases mount by one of the two upper lateral flues, and part with a portion of their heat to the boiler with which they come in contact. And lastly, a third passage conducts them through another flue, to escape up the chimney.

The object of these arrangements is easy to understand. It is to utilize as far as possible the heat arising from the fire, whether this is accomplished by the contact, or direct action of the flame, or by the gases of combustion, which, although not luminous, contain notwithstanding an enormous quantity of heat. This heat, therefore, would be entirely lost if the gases as they left the fire were allowed to escape immediately into the open air.

It is the same idea which led to the invention of the heaters. The original boilers were hemispherical on their lower side, thus presenting but little surface to the action of the fire—considering the mass of water to be vaporised. To increase the heating surface of the boilers was one of the first improvements which the constructors of steam-engines (Watt being the first) attempted to make. The object is simply to economize the fuel—a problem the solution of which, after much successful research and progress having been made, is still the desideratum in those industries which employ steam power.

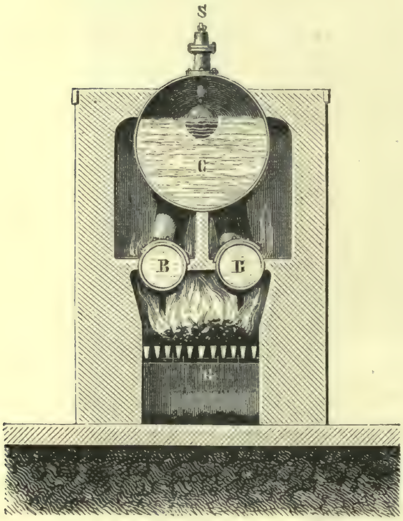


FIG. 275.—Boiler with two heaters (cross section).

It seems, after what we have just said, that if the gases of combustion, when they arrive at the base of the chimney, could be cooled down to the temperature of the external air, all the heat would be utilized, since the heat of the fuel could have been entirely extracted. But this unfortunately is impossible; or at least, if this result could be obtained, the draught and the renewal of air necessary for the continuation of the combustion would cease, or would be at least considerably diminished. If the coal burnt badly, and the heat of the furnace were not sufficiently intense, the hydrocarbon gases, which are disengaged in great abundance from the fuel, could not themselves be completely burnt. It is these that form the thick and black smoke which comes out so profusely

whenever a fresh supply of fuel is introduced into the furnace and cools it.

The hot gases, in escaping up the chimney, serve to improve the draught. It is a loss which, within certain limits, is necessary, although the direct result is neither to heat the water nor to produce steam. It thus often happens that in industrial processes an innovation, which seems to be an advance from one point of view, is retrograde from another point of view.

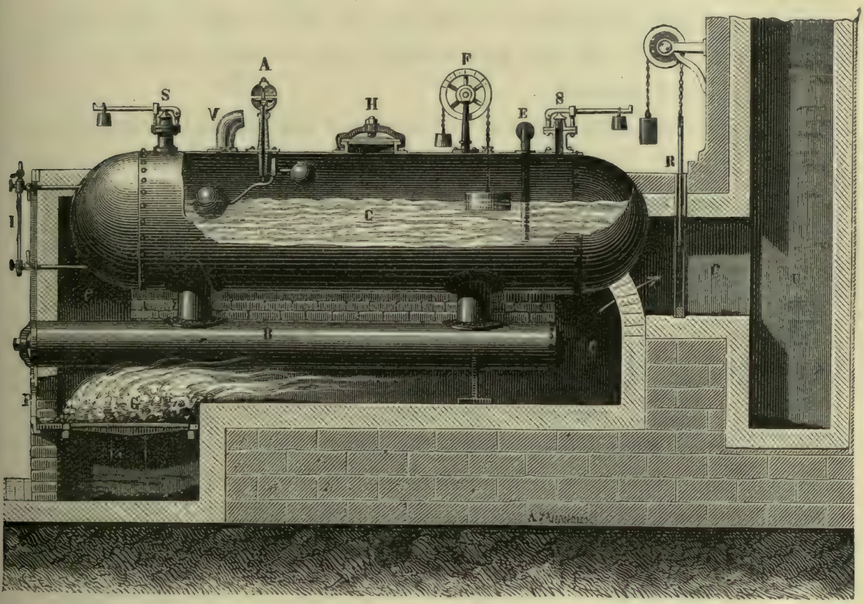


FIG. 276.—Boiler with two heaters (longitudinal section).

A. Float and alarm whistle.—B. Heater.—C. Body of the boiler.—E. Supply pipe.—F. Float to indicate the level of the water.—H. Man-hole for cleaning.—S S.—Safety valves.—R. Damper for regulating draught.—U. Chimney.—V. Steam-pipe.—C C. Flues.—I. Water-gauge.—G. Furnace.—P. Furnace-door.

It is time to say a word about the chimney, which plays so large a part in keeping up the draught. The higher the chimney is, its diameter and the rest of the conditions of combustion remaining the same, the better is the draught. It is found by experience that the height of the chimney should be proportionate to the square of the intensity of the draught.

The draught, that is, the volume of air passing, depends upon the height of the chimney and on the area of its cross section.

According to a rule given by Darcet, if the chimney have a height of twenty or thirty metres, the section ought to contain $\frac{1}{4\cdot5}$ to $\frac{1}{6\cdot5}$ as many square centimetres as it is required to burn kilogrammes of coal per hour. So that a chimney twenty metres high ought to have a section of $\frac{180}{4\cdot5}$, or forty square decimetres if the furnace is to consume 180 kilogrammes of coal per hour. Its interior diameter, if it is round, must be ·07 m., and if square, ·63 m.

Under certain circumstances the draught must be moderated. This is easily accomplished by means of a damper or movable valve, which is seen at R in Fig. 276, and by the aid of which the opening into the chimney for the smoke and gases of combustion may be diminished at pleasure.

The form and dimensions of the bars, and the spaces between them, afford elements of great importance in the good performance of the furnace, in the activity of the fire, and consequently in the vaporization of the water in due proportion to the consumption of fuel. All this must be calculated, arranged, and constructed according to the facts of science and the teachings of experience.

To conclude our account of the furnace of a steam-engine, we may say one word upon a question which has attracted some attention in industrial quarters: we refer to the possibility of obtaining what is called a smoke-consuming furnace. The true question is this, to make a furnace in which no smoke is produced, or, to speak more correctly, in which the gases, disengaged from the fuel, may be burnt as completely as possible. When the draught does not furnish a sufficient quantity of air, the incompletely burned hydrocarbons escape in the form of thick and black smoke, a very disagreeable and undesirable substance—but which manufacturers wish to retain for a much more important reason, namely, that it is the best part of the coal that is thus lost without having produced any heat.

But this great disadvantage of incomplete combustion may be still produced even when there is no smoke. For coal, besides the hydrocarbons just mentioned, which are first decomposed, as soon as the combustion commences, contains a quantity of carbon, which the oxygen transforms into carbonic oxide, and then into carbonic acid, if the draught furnishes a sufficient supply of air. If the draught is bad, the carbonic oxide escapes without having been completely burned, and it is possible in this way to lose a considerable amount of

heat in spite of the absence of smoke. In one word, a furnace called smoke-consuming is not necessarily the most economical.

To return to the boiler. We have seen what is the form of the principal body and the two heaters. The latter are filled entirely with water, which reaches to a certain height in the boiler. The free space which is above the level of the water is filled with the steam before it passes to exert its force on the machinery of the engine: it is called for this reason the *reservoir* or *steam-space*.

The steam-space ought to bear a certain proportion to the capacity of the boiler, which is found to be in practice about one-third. The reason for the large size of the reservoir arises from the necessity of drying the steam formed as much as possible, for it almost always entangles minute particles of liquid which ought not to be introduced into the cylinder. With regard to the proper size of the whole boiler, that should be made in proportion to the quantity of steam to be generated in an hour under ordinary working conditions. The force which steam at a high temperature possesses, and which is exerted first of all on the inside of the boiler, requires in this a power of resistance which cannot be obtained without certain conditions as to form, thickness, and quality of materials used. One of the best forms, as regards resistance, is the cylindrical, terminated at both ends by hemispheres. The material generally adopted is wrought-iron of the best quality, most carefully joined with rivets of great solidity. It appears that steel is beginning to be substituted for iron, but only in certain parts of the boiler: but this is chiefly a question of cost.

Some years ago in France there was an official rule to regulate the thickness of the wrought-iron plates according to the mean pressures, calculated in atmospheres, that each boiler was called upon to bear, which is interesting as showing the experience of the best French engineers. The rule in question was this: Add to 3 millimetres the product of 1·8 millimetres by the greatest working pressure expressed in atmospheres and the diameter of the boiler in metres.[1]

[1] Applying this rule to a boiler of $1{\cdot}20^{m}$ diameter, destined to support a pressure of $4\frac{1}{2}$ atmospheres, and the whole thickness would be $3^{mm} + 1{\cdot}8^{mm} \times 1{\cdot}20 \times 4{\cdot}5 = 12{\cdot}7^{mm}$.

§ IV.—SAFETY APPLIANCES.

We have supposed the boiler properly filled with water, which, when heated to the necessary temperature, furnishes to the steam-space a certain quantity of steam at the required pressure.

It is of the utmost importance that the level of the water should not sink too low in the boiler, and that it should not rise in it above a certain limit: in either case a risk is run, which is one of the most frequent causes of the explosion of boilers. To obviate this, or at least to indicate at any moment the exact level of the water in the boiler, an appliance is used called the water-gauge.

Thus you may always see on the outside of a boiler fully exposed to view a glass tube, I, which communicates by its two ends with the interior of the boiler (Fig. 276). The water has access to this tube, and stands there in virtue of the law of equilibrium of liquids.

A temporary excess of heat, or the bad working of the feed-pipe owing to a sudden accident, might quickly lower the level and surprise the engineer while he is occupied elsewhere. The water-gauge would then be of no avail. It is necessary to add one or other of the various systems of floats, which indicate the insufficient height of the level by making a noise. Such are, for example, the *alarm float* and the *magnetic float.*

A float (it is generally a hollow metal ball) rises and falls with the level of the water in the boiler. It is supported by a rod, which forms one arm of a lever turning about a fixed point; the other arm supports a counterpoise. Within the proper limits of the water level the rod holds a valve against the opening into a pipe in communication with the outer air. If the level of the water falls below these limits, the float falls with it, and causes the valve to open. The steam escapes by the tube and emerges by an annular orifice, where it encounters the sharp edge of a bell, A, which it causes to vibrate so as to produce a very intense and prolonged sound.

The stoker is warned of the danger by the unusual sound; and hence the name alarm-float given to this apparatus.

The dial gauge (F, Fig. 276) is formed of a disk, which a chain, passing round the grove of a pulley attached to the dial, sustains and

keeps in equilibrium by a counterpoise. The motion of the pulley, caused by the variations of the level of the water, communicates itself to a needle, which indicates in this way the height of the water in the boiler.

In the *magnetic gauge* of M. Lethuilier-Pinel, which is now much employed in France, the motion of the float shows itself by means of a rod which raises or lowers a horse-shoe magnet; in front of the poles of this magnet, a magnetized needle, movable under the influence of their attraction, passes over the divisions of a graduated scale which marks the level of the water in the boiler. When this level sinks to an unusual and dangerous degree, the magnet carries with it the arm of a lever that opens a valve, previously closed by a spring. The steam, which emerges freely from the boiler into the tube containing this mechanism, escapes and whistles outside, and so warns the stoker of the danger.

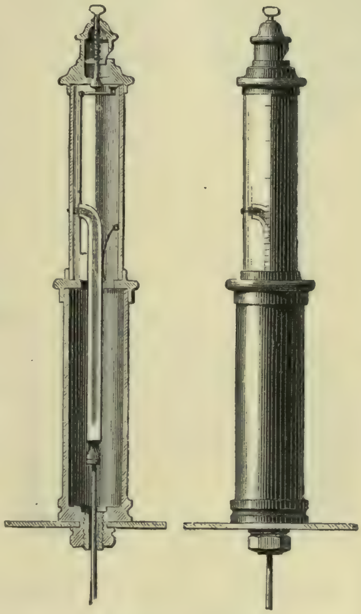


FIG. 277.—Lethuilier-Pinel's magnetic gauge.

The safety appliances of a steam-engine are not confined to the water gauges, since the causes of explosion do not arise exclusively from the insufficiency of water in the boilers. Under certain circumstances the steam might acquire an elastic force surpassing the limits of pressure for which the boiler has been constructed. To prevent this, safety-valves are used, the ordinary arrangement of which is represented in Fig. 276 at s, s.

How then can we ascertain at each instant, during the working of the engine, the variations of the pressure of the steam? The instruments which furnish this indication in atmospheres are known by the name of pressure-gauges.

The pressure-gauges employed are not all based upon the same principle. Some are simply siphon barometers, whose long

leg *b* is open; only it is not the pressure of the atmosphere that raises the column of mercury, but that of the steam; the short leg has direct communication at *a*, Fig. 278, with the steam in the boiler. The difference of the heights of the mercury in the two legs increased by the atmospheric pressure expresses the pressure of the steam.

The *compressed air gauges* (Figs. 279, 280) are nothing else than Mariotte's tubes. In one of the branches the steam freely exerts its pressure, which in the other branch is kept in equilibrium by the compressed air and the difference of level of the mercury. The instrument is regulated in such a way that the two columns of mercury are at the same height, *mm*, when the pressure of the steam is equal to one atmosphere. When the pressure gradually becomes

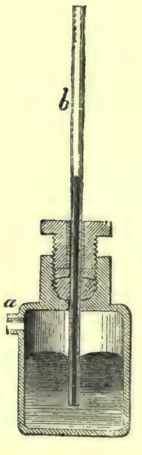


FIG. 278.—An open pressure gauge.

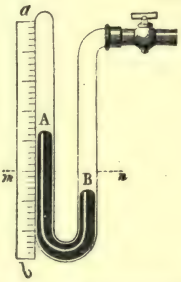


FIG. 279.—A compressed air pressure gauge.

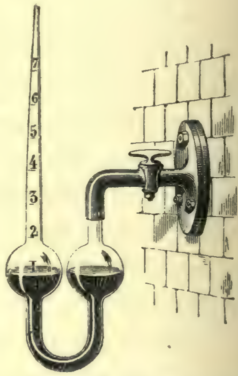


FIG. 280.—Pressure gauge with conical tube.

greater, the level rises in A, but with lessening increments for equal additions of pressure, according to Mariotte's law. The instrument is therefore less and less sensible for the greatest pressures. This disadvantage is overcome by giving the gauge the form shown in Fig. 280. The conical form of the branch which contains the air gives to the divisions corresponding to successive atmospheres lengths which are nearly equal, so that it is easier to read off high pressures than in the first system.

The handiness and cheapness of metallic pressure-gauges (Fig. 281) have caused them to be adopted for a great number of boilers. But

they do not offer the same guarantee for exactness that the others do, because the pieces submitted to the pressure of the steam may alter by use. Their action depends upon the metallic rods indicating by the greater or less curvature impressed upon them by the elastic force of the steam the value of this force, but it is necessary from time to time to submit them to verification by a comparison with more exact manometers. The disadvantage of the latter arises chiefly from the material of which they are composed, namely, glass, which gets dirty and loses its transparency, but through which one must read the mercury; their fragility forms another objection. The mercury, too, in the compressed air manometer becomes oxidised, which diminishes the volume of the air; so that the indicated pressures are greater than the true ones; they are also obviously inapplicable to locomotive engines.

FIG. 281 —Metallic pressure-guage.

Such then, in its essential parts, is the steam-generating apparatus known in practice under the name of boiler. The boiler varies much, as already stated, in its dimensions and shape, according to the kind of engine to which it furnishes the motive force. We shall notice successively the most common and most original arrangements of boilers employed for stationary engines, marine engines, and portable engines and locomotives.

§ V.—THE PRINCIPAL TYPES OF STEAM-BOILERS.

In the boiler with heaters we have just described, the boiler is over the fire—it is a generator with an exterior fire. There are also generators with interior fires, and upon this single difference we may form two types of boilers, which each divide up into numerous varieties. Lastly, we may distinguish a third type, that in which the fire properly so called is exterior, but the flues or conduits for the gases of combustion are lodged in the interior of the chamber containing the water.

The first form adopted in Watt's engines was the so-called waggon

boiler; the lower side being vaulted. The flame, after having heated the concave lower surface directly, returned upon itself by lateral flues. Later on, this form was employed in the first steam-boats, but then there was added an inner flue, through which the gases of combustion passed before entering the lateral ones. The sides of the vaulted boiler were of a bad form for resisting pressure, and the history of accidents in steam-engines shows that the greater number of explosions occurred to boilers constructed on this system. They are now gone out of use almost everywhere.

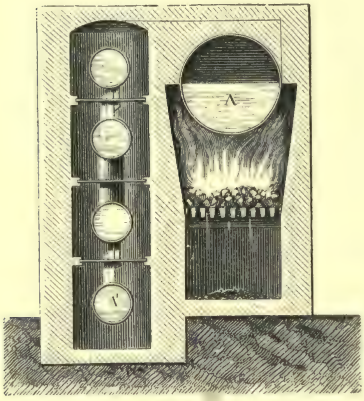


FIG. 282.—Boiler with lateral heaters. Farcot's system.

An interesting and original arrangement is that of lateral heaters in Farcot's boiler. In this system (Fig. 282) the principal cylindrical body, A, is heated directly by the fire. Four heaters are placed vertically one above the other in a side compartment of brickwork, divided into four compartments or flues, through which the gases of combustion are compelled to pass successively before reaching the chimney. The lowermost heater, A′, receives the fresh water. As the gases travel from above downwards, while the water follows an opposite path to go from A′ to the boiler, it follows that the hottest portions of the gas are in contact with the hottest parts of the sides of the boilers, and the cooler parts give up their heat to warm the still colder water before escaping up the chimney.

Suppose that the cylindrical body of a boiler incloses an inner tube of sufficient diameter entirely surrounded by water, and that we place the fire in this tube, instead of making it simply a flue like that of the boiler described above, we should then have a boiler with an inside fire. In this system the heat of the fire is entirely used and employed in the direct heating of the metallic sides of the boiler, without being absorbed by brickwork. But the heating surface will still not be large enough, unless the boiler be enveloped by flues on the outside, and then the inconvenience of a fire necessarily restricted

will not be compensated by the advantages of this arrangement. Nevertheless, we employ in England for stationary engines horizontal boilers with one or two interior fires. To further increase the heating surface the flues are frequently traversed by tubes crossing each other at right angles, and opening at either end into the interior of the boiler; these also assist greatly in increasing the resistance of the boiler to the pressure of the steam.

In the greater part of the modifications which the primitive form of boiler has undergone, the chief idea has been to increase as much as possible the heating surface, while economizing the volume and space occupied by the generator. The heaters, the inner and outer flues, the inside fire, have all been invented with the object of utilizing the activity of the fire in such a manner as to let only that portion of the hot gases pass up the chimney that is necessary to produce an ascending current, or in other words, a draught.

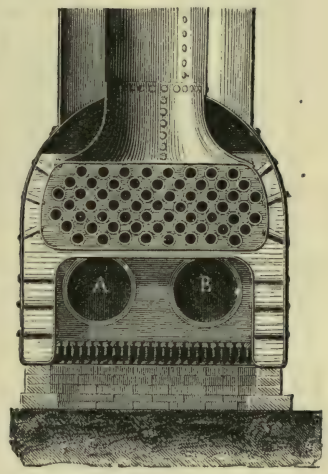


FIG. 283.—Marine tubular boiler, with return flame.

Finally, the conception has been gradually arrived at of a tubular boiler, of which the first idea is due to Barlow (1793), but which was not realized till 1829, by Stephenson and Marc Seguin. The system of tubular boilers which was first applied to railways, and has since been adopted in steamboats with some indispensable modifications, is as follows:—

In the principal cylindrical body are fixed numerous tubes parallel to each other, which open on one side to the fire and on the other side to the flues or the chimney. The tubes are bathed by the water of the boiler, which fill the intervals between them, and is heated by the gases which traverse the tubes. We shall see further on in what enormous proportion this ingenious arrangement increases the heating surface, and in consequence the steam-generating power of the boiler. In locomotives, portable engines, and marine engines, the fire is surrounded on all sides by water, except, of

course, underneath; so that the tubular boiler may also be considered as one with an inside fire. It certainly has all the advantages of one.

Fig. 283 gives an example of a marine tubular boiler, which is at the same time a boiler with return flame, since the gas from the fire before playing upon the tube passes first through two large

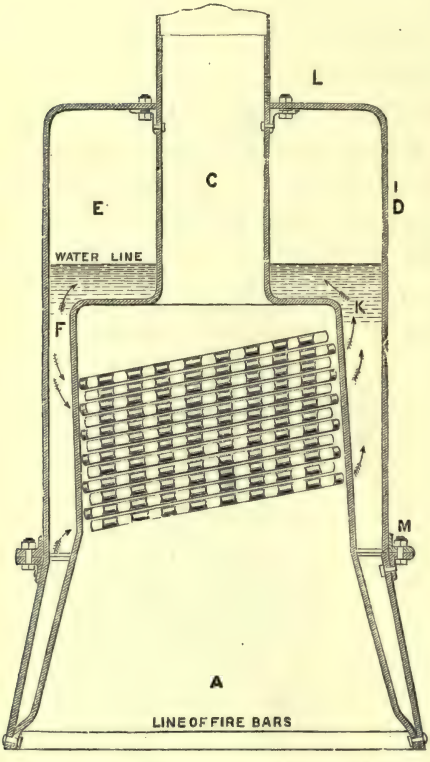


FIG. 284.—Sectional elevation of Shand and Mason's inclined water tube boiler for fire-engines.

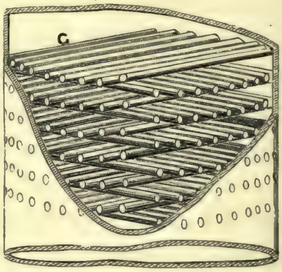


FIG. 285.—Arrangement of tubes.

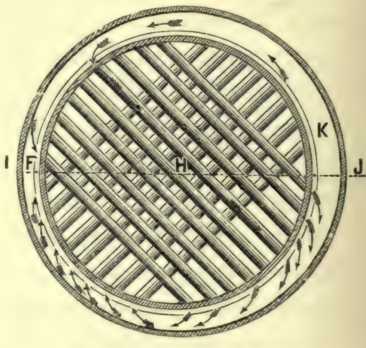


FIG. 286.—Horizontal section.

cylinders, A and B, runs back at the end of the boiler, and returns again by the tubular pipes to the chimney where it escapes.

We have in the case of the fire-engine an illustration of the manner in which such a construction of boiler is utilized when it is necessary to get up steam rapidly. Fig. 284 represents a sectional elevation of Shand and Mason's inclined water-tube boiler and in steam fire engines. A is the furnace; B the heat-absorption chamber (sectioned on the line I, J, Fig. 286); C the chimney or funnel;

D the outer shell; E the steam chest; F the narrowest part of eccentric water space from which the tubes are supplied with water at their lower ends; K the widest part of eccentric water space, through which the upper ends of the tubes deliver the steam produced from the heat absorbed by the tubes and transmitted to the water during its passage through them. The arrangement of tubes is shown at G, Fig. 285, and at H, Fig. 286, and the water spaces shown at F and K. By this arrangement a constant circulation is maintained through the tubes, in the direction shown by the arrows, and by crossing the tubes in alternate layers a constant flow towards and into the lower ends of the tubes is induced, and a constant discharge from the upper ends throughout the other half, thus causing general and uninterrupted currents of water and steam.

Besides the types just described, there are boilers in which the grate may be removed at pleasure. This arrangement offers advantages of more than one kind, notably that of rapid cleaning and removal of incrustations. There are also circulating boilers, principally formed of tubes into which water is continually and successively introduced, which vaporizes almost immediately; and there are *boilers worked by heated gas,* generally employed in connection with blast furnaces, in which the heated gases escaping from the furnace mouth are utilized.

Of all these systems of boilers we may notice one which will show us how we may construct steam-generators which are rendered, so to speak, inexplosible, from the fact that the water as soon as introduced is immediately turned into steam. Belleville's circulating boiler, Fig. 287, the use of which is spreading considerably in small and moderate-sized manufactories in the populous centres of France is one of these. It is used in many Parisian factories and printing establishments. A series of vertical tubes placed directly over the fire communicates, on one side with a horizontal pipe bringing the supply of water, on the other side with the steam pipe. Each tube is filled with water to the same height, and forms, so to speak, a little boiler half filled with water and half with steam. The flow of water to the tubes is regulated, by means of a special apparatus, by the pressure of the steam itself, so that in proportion as the water vaporizes, it is replaced by an equal quantity of water. The level in the tubes of the boiler thus always remains constant.

The production of steam is, so to speak, immediate, for a boiler of this system with a volume of less than 4 cubic metres (3·74), and with 10 square metres of heating surface, can turn 200 kilogrammes of water into steam in one hour.

There are, besides this, other systems of circulating boilers—in England, such as Scott's, and in France, Larmanegat's and Bouteguy's. We can only name them, and pass on to recapitulate in a few lines, General Morin's opinion on the respective advantages of the ordinary boilers compared with these new systems.

The first have long use for their sanction. They produce the steam required without much care or attention, and with great regularity;

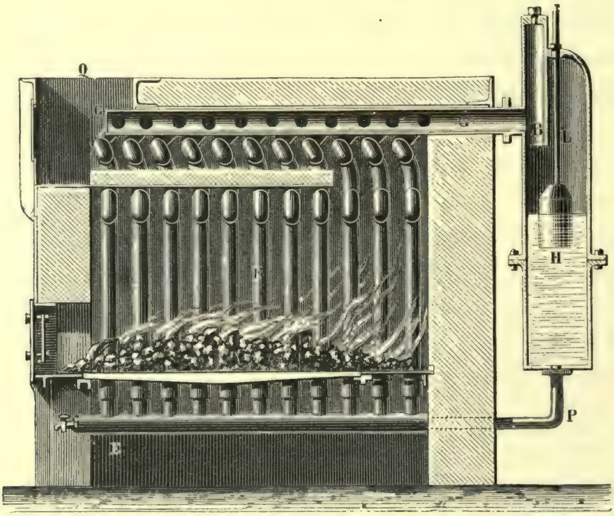


FIG. 287.—Circulating boiler. Belleville's system.

their ordinary working is simple and convenient; but they take up a great space, and are perhaps more liable to explosions. On the contrary, circulating boilers, while less cumbersome and costly, and, so to speak, inexplosible, have the advantage of a rapid generation of steam, but they require more attention, and are not more economical of the fuel. They appear to be specially applicable to engines in small factories.

CHAPTER VI.

THE STEAM-ENGINE.—THE DRIVING MACHINERY.

§ I.—The Cylinder.

THE steam being produced we will now see how its elastic force is used. The steam leaves the steam-space of the boiler by a pipe which conducts it to the inside of a cylinder, and it acts alternately on one side and the other of a piston which is movable in this cylinder, and this alternate action results in a to-and-fro movement of the piston and its rod.

The steam, coming from the boiler to the cylinder, acts first on one face of the piston, which is pushed towards the opposite extremity. At this moment the steam should enter on the other side of the cylinder, and exercise its force on the opposite face of the piston. To enable this force to act effectually we must get rid of the steam that has just acted in the contrary direction, because the elastic force which it still possesses is opposed to the motion. This object is attained by giving to the steam that has played its part an exit to the outside of the cylinder at alternate ends. The space into which it passes is either open to the air, or to a vessel exhausted of air and kept at a low temperature by a continuous flow of cold water.

In the first case, which is that of engines worked with high-pressure steam, that is, having an elastic force of several atmospheres, the steam that has done its work escapes, and its tension becomes rapidly reduced to that of the ordinary air, and thus it allows the steam to work on the opposite surface of the piston.

In the second case, the steam is quickly condensed by its introduction into an empty and cool space, which for this reason is called the *condenser*. Its elastic force, which is not much greater than

one atmosphere, instantly, or at least in a great degree, disappears, so that the chamber of the cylinder where it has just been working is itself nearly reduced to a vacuum, and the steam introduced on the other side has then no more to overcome than the resistance of the piston itself.

The various arrangements invented to conduct the steam in this way, first into the cylinder on either side of the piston, and afterwards into the open air, or into a condenser, for taking away, as soon as done with, its elastic force, constitute what is known as the *distribution of the steam;* and we will now see what are the principal systems employed for this purpose.

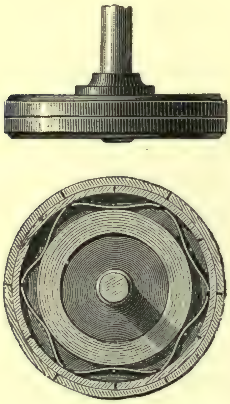


FIG. 288.—Spring piston.

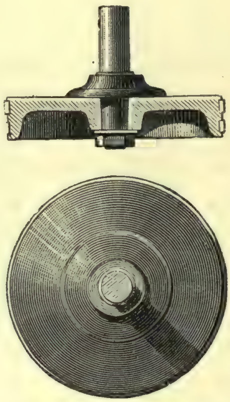


FIG. 289.—Swedish piston.

First let us speak of the cylinder, which is the most essential part of the whole of the driving machinery.

It is commonly (Fig. 290) a cast-iron box, the inside of which, perfectly cylindrical, has been turned and bored with the greatest care one of the ends is sometimes cast, sometimes firmly bolted on like the other end, so that one of the two at least may be entirely removed, in order to admit of the introduction of the piston.

One of the ends gives passage to the piston-rod, and the opening which allows this is provided with a stuffing-box, in order that the rod in its movement may not permit any escape of steam from the cylinder.

The piston itself is constructed in several different ways; most commonly it is formed of two metal plates, of a diameter a

little less than that of the cylinder, which are solidly bound together as well as to the rod which passes through them. On their circumference are situated grooves for holding the *packing*, that is, the part of the piston whose outside must glide easily, but perfectly air-tight, upon the inner surface of the cylinder, so that the steam cannot pass from one compartment to the other. The packing was formerly made of hanks of hemp, which required often greasing, and even replacing, on account of their rapid wear. For these, metallic packings have been advantageously substituted, formed of portions of a ring pressed out by springs inside, as in Fig. 288 ; and now even to these are preferred Ramsbottom's pistons, in which the body is composed of a single plate, hollowed out for greater lightness, and surrounded by two circles of soft cast-steel, fixed in two grooves round the outside and forming a spring. The surface of these circles presses against the sides of the cylinder, forming an excellent packing, which is very simple, and very little expense to keep in repair.

The Swedish pistons, Fig. 289, differ in no way from the preceding except in the breadth of the bands, which is greater, and in their composition, which is cast-iron hardened by a little tin.

§ II.—DISTRIBUTION OF THE STEAM.

The piston and cylinder being so constructed and arranged, it remains to be seen how the introduction and escape, in one word the distribution of the steam, is effected.

Consider Fig. 290, which gives a longitudinal section of a cylinder. We see in *a,a′*, near each end, the opening of a double conduit *aa, a′a′*, made in the thickness of the side; these are the openings by which the steam comes alternately and works on one side and then on the other of the piston. These are called the *steam-ports.* These two open outwards on a well-polished surface, and between the two a third opening E is seen, which serves to let the steam escape when it has done its work, and which is called for that reason the *exhaust-port.* C is the pipe by which the steam gains access to the open air or to the condenser, where it parts with its elastic force.

Now, by what contrivance is the distribution effected, consisting,

as it does, of two partial operations, the admission of the steam and its escape, which must be repeated twice to obtain a complete phase of the to-and-fro movement of the slide-valve? There are various methods employed according to the different engines—we will describe first that which is represented by the figure.

In the *valve chest* BB, is seen a prismatic box, open on one side, called the *slide-valve*. The slide-valve is applied by its open face to the well-polished plane on which, as we mentioned before, the three ports open. The space BB is called the valve-chest; the steam coming from the boiler by the pipe V spreads out freely in it, but the inside of the slide-valve, on the contrary, is always closed to the entering steam, but is constantly in communication with the escape-pipe, and also with first one and then the other of the entrances to the cylinder. Lastly, the movement of the slide-valve is produced by the engine itself, by the aid of a rod and an excentric fixed to the shaft of the fly-wheel.

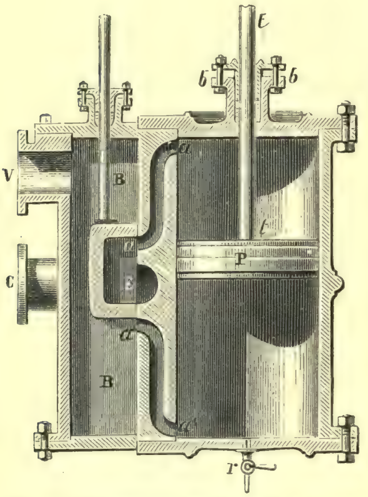


FIG. 290.—Longitudinal section of a cylinder.

By following the successive and alternating motions of the slide-valve as represented in Fig. 291 we can easily comprehend the different phases of the distribution of the steam.

This is the machinery for the distribution of steam in engines where the three-port slide-valve is adopted. But, as already said, there are other arrangements employed. There is first Watt's system of distributing valves, then there are the *piston slide-valves* of the same inventor, and lastly the D *valves*, a name due to the resemblance that the principal part bears to the letter D (Figs. 290, 291, and 292).

In the first of these three systems two valve boxes are fitted to the two ends of the body of the cylinder. Each of these is divided by two valves moved by a system of rods into three compartments, of which the middle is in direct communication with each port,

while the two others communicate, the upper with the steam-pipe, the lower with the outer air or the condenser.

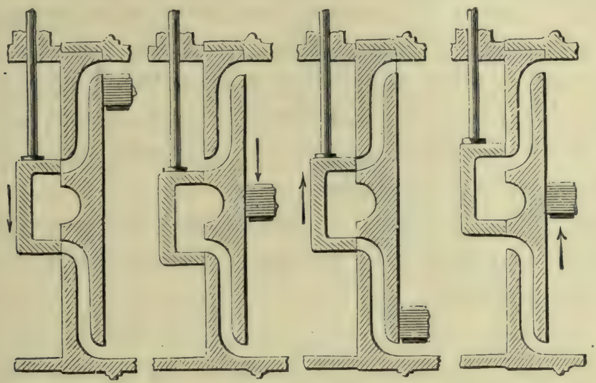


FIG. 291.—Phases of the reciprocating motion of the piston and slide-valve.

The *piston slide-valve* is so called because it consists of two pistons, moved by one rod in a cylindrical space adjoining the cylinder, which first gives the steam free access to one of the steam-entrance ports, and to the corresponding chamber of the cylinder, and then puts

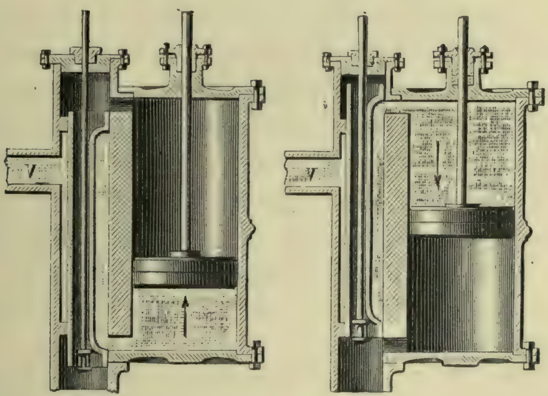


FIG. 292.—Distribution of the steam : D valve.

that chamber and the steam which has done its work in communication with the condenser.

Lastly, the D *valve* (Fig. 292) is a hollow piece moving in the steam-chest, which is applied to and slides along the face of the

cylinder by its two plane ends, where the steam-entrance ports open. The steam which comes from the boiler by the opening V can always circulate round the slide-valve without obtaining access to either of its extremities; these, on the contrary, are always in free communication with the condenser. The two plane ends of the slide-valve in their motion to and fro allow each of the steam-entrance ports in turn to receive the steam from the boiler, while the steam that has done its work upon the piston passes out by the other port, and is condensed in the condenser or the open air.

In each of these methods of distribution it is easy to understand the corresponding motions of the piston, slide-valves, and clacks in their different phases.

§ III.—Expansion of the Steam.

In giving an account of the piston and the arrangements for the distribution of the steam, it will be seen that the ports are sometimes entirely uncovered, and sometimes entirely free. From which it follows that the steam of the boiler pours with its full force upon each face of the piston during the whole time of its motion; this is expressed by saying that the steam works at full pressure.

At first no other way of letting the steam act was known; but Watt, whose name is found associated with all the principal discoveries which have transformed the primitive steam-engine, found that there was a double advantage in giving access to the steam to the piston during a portion only of the course of the piston. The result was first a much greater regularity in the motion itself, and secondly for the same amount of work a notable economy of steam, and consequently of fuel.

If the steam, for example, is introduced during the first third only of the course of the piston, it continues still to act upon it; but since the space it occupies continues to enlarge until the end, it acts by expanding, like a spring in opening, so that its force diminishes up to the end of the stroke of the piston. The steam is then said to work *with expansion.*

This mode of action of the steam is now almost universally

adopted. But before insisting on the advantages it presents, or indicating the economy of steam or of fuel which expansion secures, we must show by what modification of the distributing machinery it may be accomplished.

Here again, if we were intending to write a complete treatise on the steam-engine, we should have to describe the various systems of expansion. It will suffice however for the end in view to give an idea of one or two of the most important.

We will commence with the system of expansion called Clapeyron's, because its arrangement is due to that eminent engineer.

It consists in a simple modification of the slide-valve, or rather of the breadth of the bands which cover the ports. Instead of giving them the exact breadth of each port, they are made larger. The ledges *ab*, *a'b'*, *cd*, *c'd'*, inside and outside form what is called the *laps* of the slide-valve, because it is the object of these overlaps to shorten the time of admission of the steam into the cylinder through each

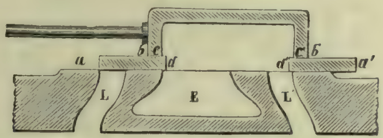


FIG. 293.—Clapeyron's expansion system: slide-valve with laps.

of the two ports. It would be necessary to enter into too long and technical details to follow the motion of the expansion-slide valve through all its phases, and to show clearly what is the action of the steam in each of these phases. But we can sum up the whole action by saying that each introduction of the steam into the cylinder gives rise to four successive periods, which we will characterize.

In the first period there is the admission of the steam, which works during that time at its full pressure, that is, with the pressure of the steam in the boiler, after which a steam-entrance port is closed.

In the second period there is the expansion of the steam admitted, which then works with a decreasing force until the moment when the steam-exhaust port opens.

The escape of the steam occupies the third period, but since from the existence of the laps the escape ceases before the piston has reached the bottom of the cylinder, there remains a certain quantity

of steam in it, which the piston drives back and compresses before the commencement of the new period of admission.

Clapeyron's expansion system is chiefly employed in engines for rapid motion, such as locomotives.

In Meyer's expansion system the slide-valve is pierced by two orifices, which are brought alternately into communication with the entrance ports, and there are two plates, having a motion independent of the slide, which come and close these orifices, so as to stop the admission and start the expansion.

Lastly, in Woolff's system the expansion does not take place in the cylinder itself, but in a cylinder of greater diameter placed close

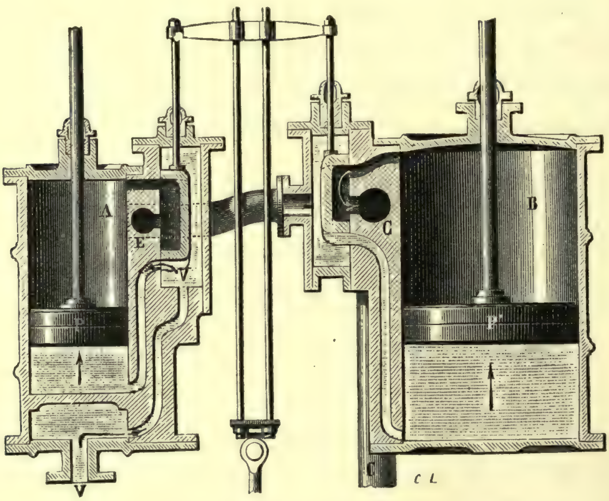


FIG. 294.—Section of the two cylinders in Woolff's expansion system.

to the first (Fig. 295). It is for this reason that engines which employ this method of expansion are called double-cylinder engines.

Fig. 294 shows the distributing machinery in these engines.

Each of the two cylinders A, B, is provided with a valve-chest in which an ordinary slide-valve works, with entrance and exhaust ports as usual.

The steam comes from the boiler by the orifice V, which opens first into the chest of the cylinder A, and thence passes, say, below the piston P. This piston receives an upward motion, and drives back the steam which was on the other side into the outlet pipe E, a pipe

which, instead of communicating with the condenser, as in the single-cylinder engines, goes into the steam-chest of the cylinder B. Thence it enters by the lower valve-entrance port below the piston P′; and in expanding it also produces the elevation of the piston; as to the steam which is on the other side in the upper chamber of the cylinder, it goes as usual to the condenser or the open air through the pipe CC.

The simultaneous motion of the two slide-valves in opposite directions will give rise to an upward motion of both pistons, the

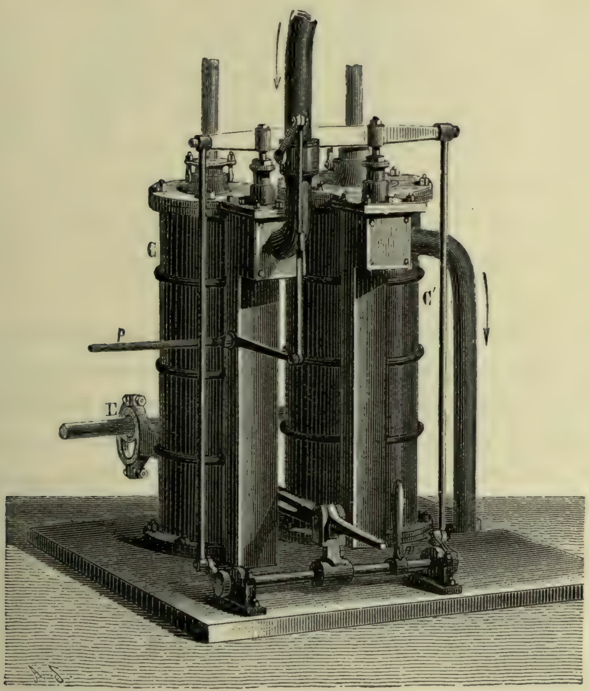


FIG. 295.—Woolff's system of distribution and expansion: the two cylinders.

steam acting at full pressure in the small cylinder, while in the large cylinder it acts only by expansion. In the more modern form of double cylinder, more properly *compound engines*, the steam in the high pressure cylinder is cut off at from three to four-tenths of the stroke, and is allowed to work expansively throughout the remainder. It is then admitted into the low-pressure cylinder, and having done

its work there it passes into the condenser. The pressure in the condenser cannot quite be reduced to zero practically, but in good performance the remaining pressure of the steam does not exceed three inches of mercury, or about twenty-seven inches less than that of the atmosphere; this would be technically known as twenty-seven inches of vacuum.

§ IV.—The Transmitting Machinery.

It remains to show how the motion of the piston is transmitted; by what machinery it is transformed, regulated, and kept constant. The problem to be solved is not peculiar to steam-engines, any motive power may give rise to the same question. "Given the to-and-fro motion of the piston-rod, or reciprocating motion, as it is called, to find a method of transmission which shall change it into a continuous circular motion, which may turn, for example, a main shaft, in the motion of which all the partial motions required in the factory may share."

The oldest, which is still adopted in a great number of cases, are the *beam-engines*, of which Fig. 296 shows the principle.

The rod *t* of the piston, whose lower extremity describes a vertical straight line, is jointed at the other extremity to a great oscillating bar, or lever, AB, which is made to move (in a vertical plane) about a fixed axis I. This piece is the *beam*, to the other extremity of which a connecting-rod is jointed, which works in its turn a crank, attached at O to the axle to be put in motion. Owing to this arrangement the alternate rectilinear motion of the piston is transformed into a continuous circular motion of a wheel. Here the beam is above the piston-rod, but it can be also placed below, and we shall see examples of that arrangement in the marine steam-engines.

By the beam, the connecting-rod, and the crank, the alternating and rectilinear motion of the piston is transformed into a continuous circular motion; but this transformation is not direct, for the extremities of the beams in oscillating each describe an arc of a circle, first in one direction and then in the other, so that the motion is at first circular and alternating. It is the connecting-rod and the crank which complete the transformation, and produce the continuity of the

circular motion. It follows from this that the piston-rod, which moves vertically, cannot be directly joined to the end of the beam, because this would force it to follow the arc of a circle, and hence would turn it sometimes to the right and sometimes to the left. To remedy this disadvantage, which would render the engine impractic-

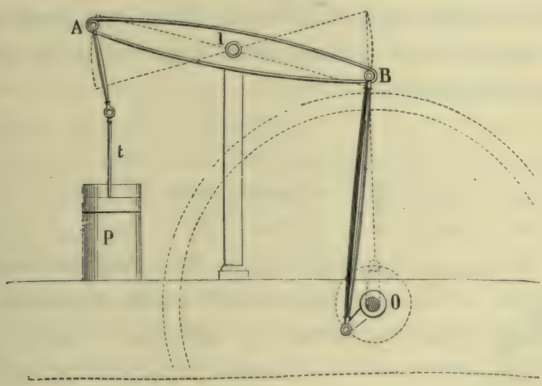


FIG. 296.—Principle of transmission in beam-engines.

able, Watt invented a very ingenious system of joints, known as Watt's parallel motion, of which the following is a short description.

The piston-rod, instead of being joined directly to the extremity E of the beam, is joined to the point D of the parallelogram CBDE, whose four sides, though rigid and invariable in length, are jointed

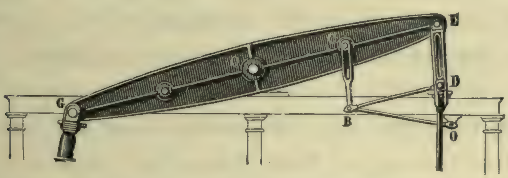


FIG. 297.—Watt's jointed parallelogram.

at their extremities, so that the angles vary according to the oscillations of the beam. Moreover, the point B is attached by a rod BO to a fixed point O in the immovable framework of the engine. The relative lengths of these different lines are calculated in such a way that the point D describes very nearly a vertical straight line, while the points C, E, B, describe arcs of circles having for their centres the

two points O, O. The oscillation of the beam, that this result may hold, must not exceed the limit of 20° on one side or the other of the horizontal. The middle point of the side BC has the same properties as D; and this fact is also made use of in Woolff's engines, where the pistons of the two cylinders must move together.

It is to be understood that the arrangement just described is repeated on the other side of the same end of the beam, so that in reality the piston-rod is jointed to a horizontal axis, which passes though the double point D.

§ V.—Regulators.

It will be seen, on referring to Fig. 299, that on the axis, moved by the system of connecting-rod and crank described above, is mounted a large wheel V, generally of cast iron, which is called the fly-wheel. This piece, which is found in all driving engines, is for regulating the motion.

In a driving engine, the velocity is subject to variations, which may depend either on the motive force itself, that is, on the steam which comes from the generator more or less abundantly, and possessing a pressure of greater or less degree, or on the employment of the force in the factory where the engine is set up. It is easy to see that it is advisable to have these variations kept within narrow limits, which may be accomplished in various ways; and one of these ways is the employment of fly-wheels, which increase the mass of the movable parts of the engine. When there is excess of velocity the mass of the fly-wheel absorbs the excess of motive power from the form of moving force, and restores it to the various parts of the engine when the motion relaxes. The fly-wheel is made both of great weight and large diameter, and the greater part of its mass is concentrated in the rim that forms its circumference.

The dimensions and weight of the fly-wheels are calculated according to the power of the engine, and the greater or less irregularity of the motion, and the resistance to be overcome.

The use of a fly-wheel to regulate the motion of a steam-engine does not fulfil its object unless the velocity is sometimes greater and sometimes less than the normal velocity. But if there be any reason

to fear that the velocity may be always in excess or always in defect, the fly-wheel is of no use, for it will itself acquire a too great or too little velocity, and this excess in the first case may go on increasing up to breaking point. The centrifugal force, which increases with the square of the distance, would be the cause of this accident, and this foreshadows the use of another kind of regulator, we mean the *centrifugal regulators,* by the aid of which the engine itself regulates its velocity in case of the steam leaving the boiler with excess of pressure, or of the steam not arriving in sufficient quantity, and the velocity of the motion diminishing.

This apparatus consists of two metallic balls B, B, carried by two rods OA, OA′, jointed to a fixed point O on a vertical axis. Two other rods, jointed at A and A′, are attached to a collar M, which clasps the vertical axis and moves up and down along it. The whole system receives also, through the intervention of a pulley P, the motion of rotation given to the driving-shaft of the engine. Lastly, the collar M is clasped by a fork forming the end of one of the arms of a lever I L.

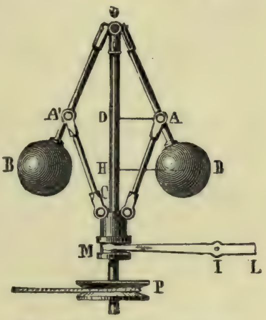


FIG. 298.—Watt's centrifugal regulator or governor.

When the engine is working with its required velocity the lever ML remains horizontal. If the velocity increases, the centrifugal force lengthens the distance of the balls from the axis, the collar rises, and with it the arm of the lever IM. The other arm, IL, is lowered by its turning about the point I. If, on the contrary, the velocity diminishes, the centrifugal force is less; the balls approach the axis, which depresses the collar, and produces an opposite motion in the lever.

In the steam-pipe (the pipe supplying the cylinders with steam from the boiler) is placed a valve consisting of a flat disc, moving about an axis passing through its centre and lying in the plane of the disc. To the extremities of the axis is rigidly attached a forked lever; when this is placed in one position the disc is at right angles to the length of the steam-pipe and completely closes it; when moved from this position it causes the disc to open the passage of the steam-pipe; and when the lever is in a position at right angles to the first, the

whole area of the pipe is free for the passage of the steam. This is called the *throttle valve.* The other arm of the lever, moving the valve, is connected with the end L of the lever ML in such a way that as the collar M rises, lowering the point L, the valve is turned more across the steam-pipe, thus reducing the area of the steam-passage and lowering the speed of the engine. The flow of steam is therefore diminished when the velocity of the engine passes the normal limit; it is introduced, on the contrary, in greater abundance when there is a falling off.

Two other systems of regulators are employed besides these, the arrangement of which is very slightly different from that of the centrifugal regulator (known also by the names of Watt's governor). Both are founded, like the first, on the action of the centrifugal force applied to masses which turn on an axis set in motion by the engine.

CHAPTER VII.

VARIOUS TYPES OF STEAM-ENGINES.

§ I.—WATT'S BEAM-ENGINE.

WE come now to the machinery for transmission. We have to examine how the motion either of the beam or the shaft is utilised by the working of the slide-valve and of the feed and exhausting pump.

To the shaft of the engine is fixed an excentric seen at *dd* in Fig. 299, the function of which is to produce the alternate motion of the slide-valve. It is very easy to explain how this result is obtained. The excentric is formed of a circular metallic disc, which is pierced by the shaft at a point which is not its centre. Its motion of rotation involves that of a collar or band in connection with a long metallic triangle. Now the extremity of the latter is attached to one of the arms of a bent lever, the other arm of which carries the rod of the slide-valve. The oscillating motion of the lever produced by the rotation of the excentric gives rise to an alternating vertical motion of the rod, and the slide-valve works as we have seen above.

Figure 299 represents the beam-engine, as it came from the hands of Watt, with all the improvements that that illustrious mechanician successively made in it; it gives the reader a general view of the various mechanical arrangements with respect to the distribution and transmission that we have had to describe separately and in detail. It remains for us now to show how the various pumps, which we have mentioned in our description of the engine, work. H is the condenser which is bathed in a cistern of cold water RR, and which receives water from that cistern by the pipe *t*. Since the condensation of the steam cannot take place without its giving up to the

water the latent heat of vaporisation, the water in the condenser is constantly being heated, and it is necessary to replace it as constantly by a fresh supply of cold water; whence the need of the exhausting pump E, which is worked by a rod attached to the beam; this pump returns the condensed and warm water to the chamber R′, and there the feed-pump W acts, raises the water, and sends it on to the boiler; Y, the rod of that pump receiving its motion from the beam.

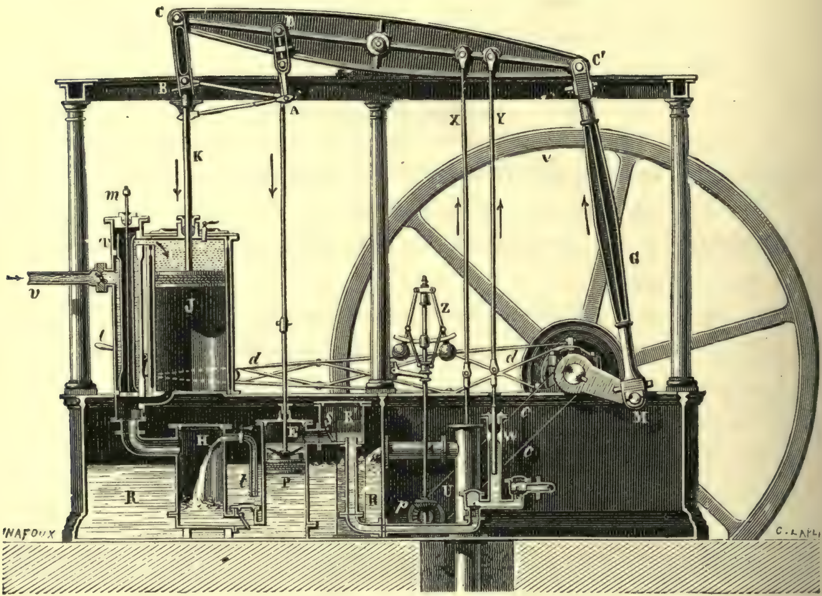


FIG. 299.—Watts' beam engine.

v. Steam-pipe.—T. Slide-valve.—J. Cylinder.—H. Condenser.—PE. Exhausting or air-pump.—WY. Feed-pump of the boiler —UX. Feeding pump of the cistern R.—*p*Z. Governor.—*dd*. Excentric. ABCD. Parallelogram.—GM. Connecting rod and crank.—V. Fly-wheel.

Lastly, we see in X the rod of the pump U, which serves to feed the cistern RR with cold water. This pump, generally more powerful than the other two, obtains the water from some neighbouring source, such as a spring, a tank, or a river.

This complication of parts, and accessory apparatus, which moreover derive all their motion from the steam-engine, only occur in the condensing engines, that is, those which work at a low pressure. In engines at high pressure, whether fixed or movable, the condenser, the exhausting pumps, and all the machinery connected with

them, are suppressed. There is nothing but the feed-pump. But we have purposely taken for our type the most complicated steam-engine, so as not to forget anything that is essential for the explanation of the machinery employed in the different types.

§ II.—Steam-engines with Direct Motion.

The transmission of the motion in the beam-engine is made indirectly, since the motion becomes alternating and circular before it becomes continuous.

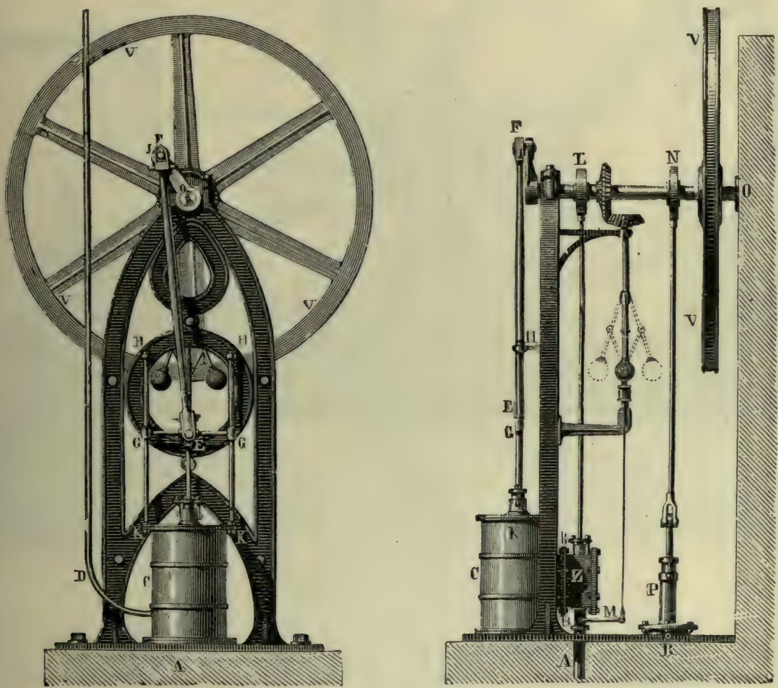


Fig. 300.—Vertical steam-engine.

A. Steam-pipe.—C. Cylinder.—BZ. Slide-valve and valve-chest.—GKH. Slide.—EFJO. Connecting-rod, crank and shaft.—VV. Fly-wheel.—PO. Feed-pipe.—D. Blast-pipe.

Many methods have been invented for the direct transmission of the motion of the piston to the shaft; whence the engines known as vertical, horizontal, and oscillating. We will explain a type of each of these kinds of engine.

The *vertical engine*, or engine with vertical cylinder, two views of which are given in Fig. 300, is a high-pressure engine, in which the steam acts by expansion, but without condensation. The explanation of the figure shows what are the various parts—the cylinder, the slide-valve, the fly-wheel, the governor, &c. The only point to which we would draw attention is the method of transmitting the motion.

The piston-rod is directly jointed to the connecting-rod EF, which works upon the crank of the shaft. This rod is guided in its motion

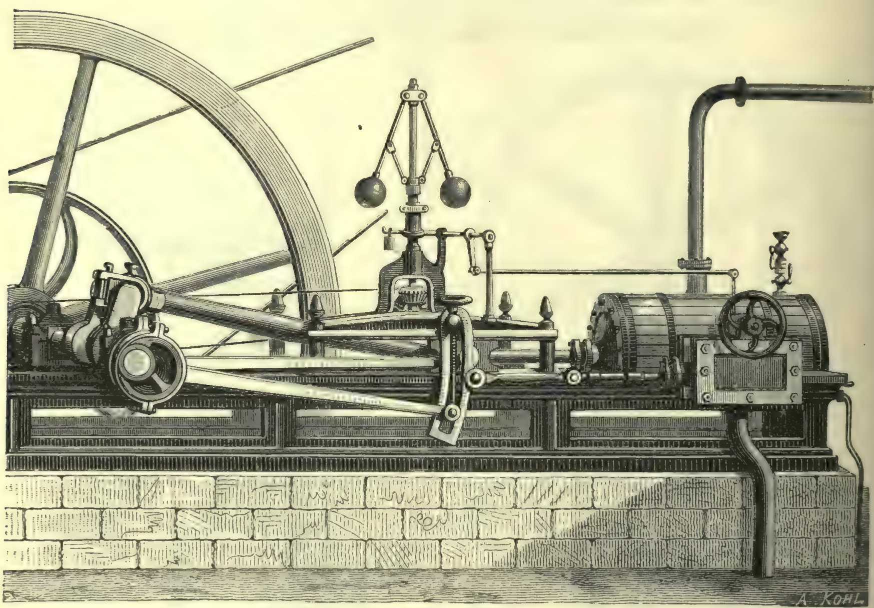


FIG. 301.—Horizontal steam-engine.

by a cross-head, or horizontal movable bar GG, which moves up and down two vertical guides, which are fixed at K and H, that is to say, at K to the cylinder and at H to the framework of the engine.

This is, indeed, a mode of transmission, very similar to that of the horizontal engine represented in Fig. 301; and we have said enough about it to enable the reader to understand, without any special description, the arrangement of the different parts of the engine.

In locomotives we shall see that sometimes horizontal and some-

times inclined cylinders are employed; the reasons for preferring one or other of such arrangements, which involve nothing essential, have relation either to the construction and general working of the parts of the engine, or, in fixed engines, to questions of the horizontal or vertical space available.

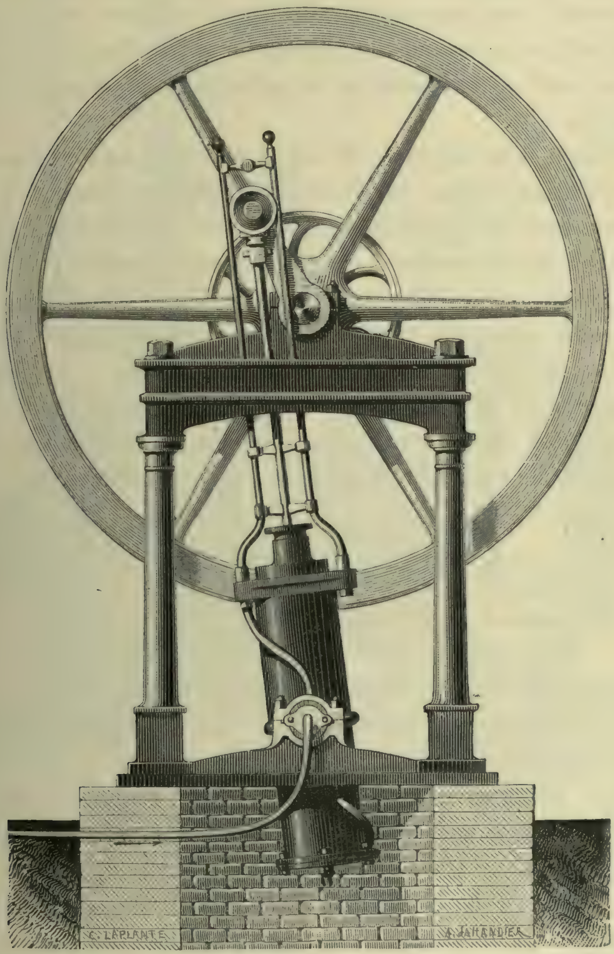


FIG. 302.—Oscillating steam-engine.

In trunk-engines, the piston-rod is suppressed, and the connecting-rod is directly jointed to the piston itself. The oscillating motion of this rod takes place in a cylindrical sheath or collar, which passes

through the cylinder and which the piston completely surrounds. This arrangement diminishes the surface of the piston exposed to the action of the steam, and this diminution must be compensated by increasing the diameter of the cylinder. The disadvantage of this very simple arrangement is easy to understand: for one thing, the steam is more quickly chilled, because the surface exposed is more considerable; and for another, leakages are more easily produced both round the collar and the grooves in which the piston moves.

This kind of transmission is principally employed in English steamships.

A French manufacturer, M. Carré, invented and constructed the first oscillating engine, in which there was no connecting-rod, the piston-rod itself being jointed directly to the crank of the shaft.

The cylinder of oscillating engines is supported by two trunnions, like a piece of artillery on its carriage. The trunnions are hollow, and serve, one for the steam port and the other for the exhaust port. In other respects the distribution is regulated by a slide-valve as in ordinary engines. A distinction is drawn between horizontal and vertical oscillating engines, according to the mean direction of the cylinders in their successive oscillations.

§ III.—Rotatory Steam-engines.

It still remains for us, while studying the various types of steam-engines, to speak of a kind of engine which differs from all the others that we have passed in review up to this point in the very principle of its machinery. We mean the rotatory engines, so called because the part on which the steam acts directly, or which corresponds to the piston in the cylinder engines, receives a motion which is directly circular and continuous. The problem of the transformation of the motion is not involved in these engines.

The idea of solving the question of motion by steam in this way is not new. It occurred to Watt in 1782; but the disadvantages of this arrangement have not encouraged large manufacturers to assist in improving the tentative essays in this direction: even now, in spite of the improvements introduced in the construction of rotatory engines, it is only in very special cases that they can be made use of in practice.

We will do no more than mention the disc rotatory engine invented by Bishop and constructed by Rennie;[1] since to understand its very ingenious arrangements, which are difficult, however to follow, even with the help of a figure, would require too long a description. We

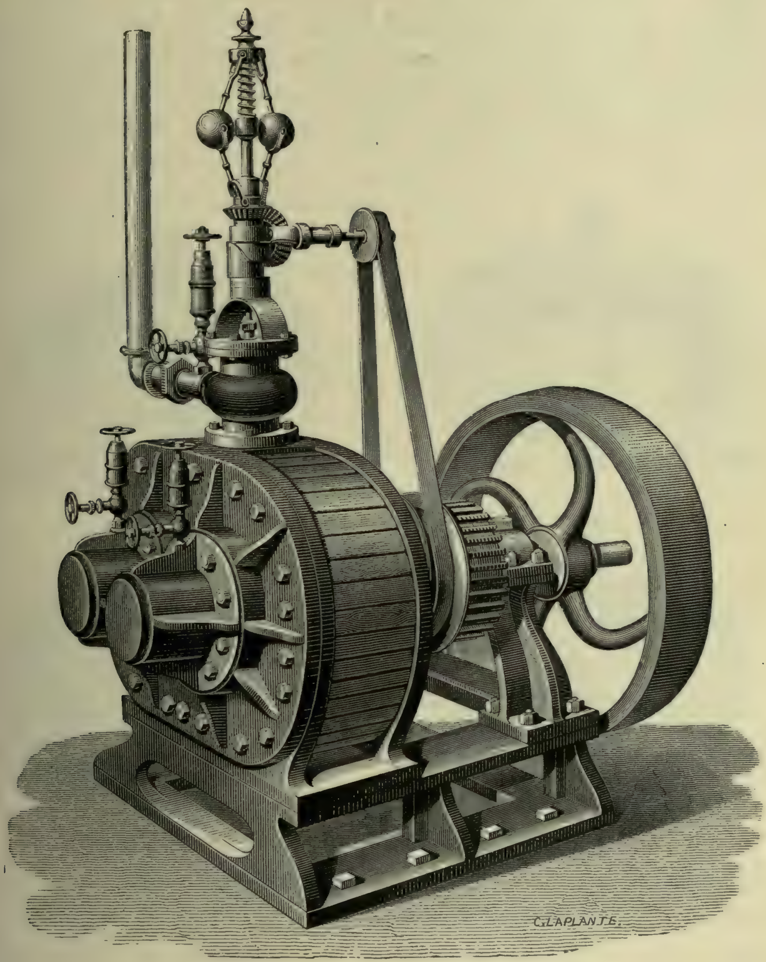


FIG. 303.—Behrens's rotatory engine.

will only describe the one that has been adopted in the Russian navy, for their gunboats and small screw steamers.

The rotatory steam-engines by Behrens, of America, which was to

[1] See on this subject Sonnet's *Dictionnaire des Mathématiques Appliquées.*

be seen in action in the Paris Exhibition of 1867, is much simpler, at least for description. Fig. 303 gives an external view. The method of working and the arrangements of the moving parts and the distribution are as follows.

On two parallel shafts, CC, are mounted two pieces in the form of a portion of a crown, both edges being concentric with the corresponding shaft and fixed by one of the extremities on a shoulder of the latter. These pieces play the part of the piston in ordinary engines. Their outside convex surfaces fit into an accurately bored

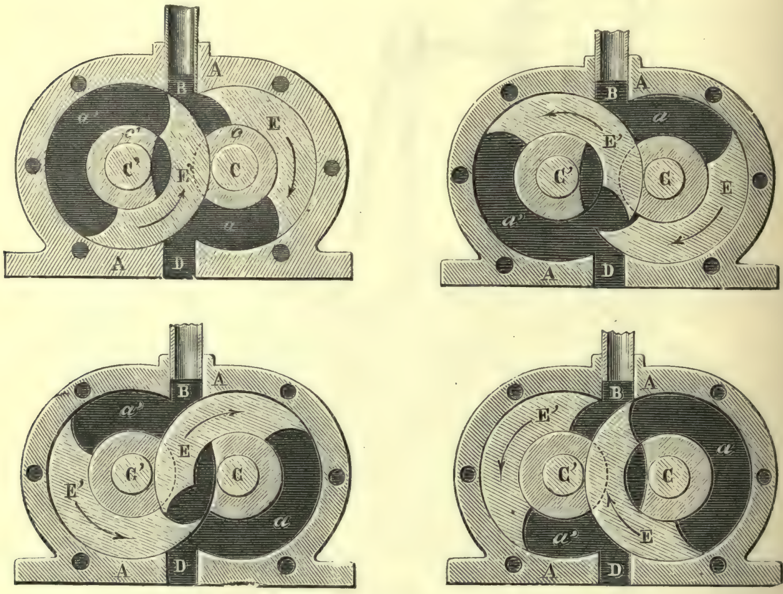


FIG. 304.—Rotatory engine: phases of a complete motion of rotation.

cylinder, AA, and their inside concave surfaces move round two sockets, CC, concentric with the shaft. The form of the different pieces is calculated, so that each of the pistons in its motion may work through a groove concentric to its own axis of rotation and hollowed out of the fixed socket of the other piston. The result of this arrangement is that the steam can never pass between one of the pistons and the socket of the other. We will now see how the steam works.

It arrives by the supply pipe, B, from the boiler, and enters the

space between the two pistons and the socket C. Supported by the convex surface of the piston, E′, it pushes the concave surface of the piston, E, and turns that piston and its axis in the direction marked by the arrow. Since the two axes carry some cogs on the outside, which make them turn in opposite directions, and with the same velocity, the axis, C′, and its piston move inside in the opposite direction to the first. The second and third figures of 304 show the position of the pieces after a quarter and half a revolution. At this instant the piston, E, closes the opening B; the steam can no longer act on that piston, but it begins to act on the other. Before the commencement of the third quarter of the rotation (phase 4), the opening of the exhaust port, D, is uncovered, the steam in the space, *a*, escapes, the piston, E, is kept in motion by the other axis and its acquired velocity, and so on for the rest. The steam thus acts on each piston for a little more than half a turn, and each of the axes receives its motion from the steam itself and the other axis with which it is in connection; one of these axes is the shaft of the engine, the other has a fly-wheel. Behrens' rotatory engine is obviously a steam-engine without expansion and without condensation; though it is possible, by means of a suitably adjusted valve, to make it work by expansion.

We have already noted (p. 57, Book I.) one of the original applications of this engine, which consists in employing it to work a pump constructed on the same principle and working in the same manner. In the United States it is used in breweries and refineries as a force pump for the various liquids, such as water, beer, syrup, &c. It is little used in Europe, though it is obviously an engine of a certain industrial importance.

§ IV.—The Power of Steam-engines.

Such is the modern steam-engine as a whole, and in the principal details of its structure.

To sum up in a few lines the description which has been the object of the last three or four chapters, we see that the steam-engine consists of:—

First, a boiler or steam-generator, which transforms into an

available elastic force the energy contained in the fuel, such as coal. Heat is the agent of this transformation, it passes from the fire to the substance which forms the heating surface of the boiler, and is communicated from the iron to the water, the temperature of which it elevates, causing and maintaining ebullition, and continuously supplying the steam space with a gaseous and elastic mass at a pressure necessary for the work to be done. The fire, the grate, the ash-pit, the flues and chimney, the heaters and body of the boiler, valves and safety apparatus, pressure gauges, and water and steam gauges—such is the generator of the engine with its accessories.

Secondly, the steam being produced, the engine properly so called, is composed of machinery for motion, of receivers of the energy, and of apparatus for its distribution, having for their object, the production of alternating rectilinear motion. The cylinder, the steam chest, the slide valve, the condenser, are the principal structures in this part of the engine. It forms the driving machinery.

Lastly, the motion once produced under its first form, it is necessary to transform it, and render it fit for the work which is required, and this is most often in the form of a continuous circular motion. The connecting rods, cranks, beams, slides, are the pieces ordinarily employed in this part of the engine to which the name of transmitting machinery is applied. The fly-wheel and the governors have a special object, that of keeping the velocity of working within definite limits.

These different functions being well understood, and the apparatus connected with them being clearly conceived, at least in their principal arrangements, we can next proceed to the examination of the different types of engines which have been invented since the first use of steam, and which are now used in great numbers in manufacturing industries, on railways and in steamships, and even in agriculture.

Before reviewing these types, and showing the steam at work in the many services it renders to civilization, we must be allowed,—not a digression, because it concerns something essential,—a short explanation of certain terms and expressions frequently employed in speaking of engines and estimating their power.

The power of an engine does not depend only on the pressure per square inch of the steam which moves it. This is merely an element.

Account must be taken of the dimensions of the cylinder and the number of strokes of the piston that the engine gives per minute or per hour, a number which itself depends on the quantity of steam regularly furnished by the boiler. In this way the work of the steam on the piston may be estimated. But this work in being transmitted to the shaft and the fly-wheel is partly absorbed by the friction and resistance of the machinery of transmission, so that it must be reduced according to experimental rules to obtain the real work done, or the effective force of the engine.

This work is estimated in horse-powers. Thus we speak of an engine as being of 3, 4, 10, 50, or 500 horse-power.

Before going further we will explain clearly what is meant by this expression, "horse-power."

Horse-power is the unit introduced by Watt for the measurement of the *rate* at which work is being done. One horse-power (1 H. P.) is equal to 33,000 foot-pounds of work done in one minute. We have thus three units involved in the definition. A foot pound is the amount of work done in raising a pound weight one foot high against the action of gravity. Work is measured in foot-pounds. To take an example. The traction of a horse drawing a carriage is measured and found to be 37·5 pounds when going at the rate of ten miles an hour. To find the H. P. of the horse.

$$10 \text{ miles per hour} = \frac{3 \times 1760 \times 10}{60} = 880 \text{ feet per minute}$$

$$\text{H. P. of horse} = \frac{\text{Traction} \times \text{feet traversed per min.}}{33{,}000} = \frac{37.5 \times 880}{33{,}000} = 1.$$

Thus a horse going at the rate of 10 miles per hour and exercising a constant traction force of $37\frac{1}{2}$ lbs would be doing work at the rate of 1 H. P.

The use of this term arose in this way.

When Watt had adapted to his first steam-engines such improvements as enabled them to be used in mines and manufactories, the constructors of the engines found themselves obliged to guarantee to their customers the power of the new engines. In mines, horses were generally employed to turn the windlasses. The mean daily work of these animals was taken as a term of comparison, and an estimation made experimentally by Watt of the power of the engines sold was expressed in horse-powers. An amount of work was thus arrived

at which is expressed as 33,000 lb. raised 1 foot in a minute. But we must not make a mistake. The work of the steam is supposed continuous, and the engines work night and day without resting. An engine of one horse-power does in a day of twenty-four hours 1440 times this work, but a real living horse, on the contrary, requires to rest, and if he works for eight hours a day he will not do more than one third of the work of the engine.

In reality this value is still too high. Watt's figures, if we may judge by more recent experiments, were applicable to horses of more than ordinary power, and these were probably overdriven. It follows from the experiments to which we have alluded that a horse of ordinary strength, walking for eight hours turning a windlass, would do only 17,820 foot-pounds per minute.

We see then, on a comparison of the two sets of figures relative to the work of the engine and that of the animal, that in reality, to replace an engine of one horse-power, in order to turn the same windlass without ceasing, a little more than five horses and a half must be employed.

What constitutes the power of a boiler is the quantity or the weight of steam that it is capable of producing in an hour when in full work. Now it is chiefly on the heating surface that this quantity depends, so that other things being the same, the generator that offers to the fire and the gases of combustion the largest amount of heating surface is the most powerful.

With regard to the consumption of coal, it is evidently in relation to the heating surface, but it varies from one engine to another, according to the type of the engine, whether it works at high, low, or medium pressure, and whether it works with or without a condenser, with or without expansion. Experiment shows the following facts.

It is found by practice that for each horse-power, the heating surface varies from 10 to 15 square feet. A steam engine of 10 horse-power must have a generator with a heating surface of from 100 to 150 square feet. The quantity of steam produced in an hour is, on an average, 44lb. per horse-power, so that the boiler of an engine of 10 horse-power should be able to convert into steam 440lb. or about 44 gallons of water per hour.

As to the consumption of coal per hour and horse-power, it

varies, as we have said, with the engines. Watt's low-pressure engines consume from 11 to 13lb. of coal, Woolff's, about 6lb; high-pressure engines, with expansion and condenser, consume from 8 to 11lb. per horse-power in an hour. These are the least economical, but they counteract that defect by the advantages we shall mention presently.

A word now with regard to the power of an engine in relation to the dimensions of the cylinder and the velocity of the piston, or which comes to the same thing, the number of strokes of the piston per minute or per hour, the pressure of the steam being known by the reading of the manometer.

How may the work done by the piston during its stroke in the cylinder be calculated? We will take an example which will explain both the question and the reply that must be made to it. Suppose there is a pressure of 4 atmospheres in a condensing engine, or of 5 atmospheres in an engine without a condenser. The energy exerted by the steam will in reality be the same in both cases, since in the second the atmospheric pressure acts on the opposite face of the piston to that on which the elastic force of the fluid acts. It is found that for every square inch of the surface the work of the steam will be about 15lb., multiplied by 4, the number of atmospheres. This must be multiplied again by the number of square inches the surface of the piston contains. But this does not give the mechanical work, which will be greater or less according to the length of the cylinder or the excursion of the piston. To have the work in foot-pounds, the result must be multiplied by that length, so that we have the following rule.

Multiply the surface of the piston in square inches by its stroke expressed in feet, by the effective pressure of the steam (that is, the excess of the pressure one side over that on the other), and by fifteen, and you have the number of foot-pounds which measure the work done by the piston in each excursion. But the surface multiplied by the length of the cylinder is the volume of the latter.

Thus the work done is proportional to the pressure of the steam and the volume of the cylinder. Suppose the diameter of the cylinder is sixteen inches, and its length is fifteen inches. In this case the engine is condensing, and let the vacuum of the condenser be assumed perfect. Then steam pressure is $4 \times 15 = 60$ pounds per square inch

above the atmospheric pressure, and the vacuum is 15lb. per square inch below it. Thus the excess of pressure is 75lbs.; the work in one excursion of the piston will be $\pi . 8^2 \times 75 \times 1\frac{1}{4}$ foot-pounds, or about 18,800 foot pounds. The whole to-and-fro motion of the piston then would do 37,600 foot-pounds of work.

This gives the work of the engine for one to-and-fro motion of the piston, so that we must know besides the number of these motions which take place in a minute or hour to find definitely in horse-powers the power of the engine.

This velocity of the piston is very variable, but it seldom exceeds sixty strokes a minute or a stroke a second. If it works with its maximum velocity, the power of the engine would be 37,600 foot pounds per second, or about sixty-eight horse-power.

§ V.—Historical Sketch of the Steam-engine.

The first steam-engines actually employed in practice were those of Savery (1696—1698). Their principle had been given by Papin, since, as Arago says, "Papin was the first who attempted to combine in one heat engine the elastic force of steam with the property that steam possesses, and which he pointed out, of condensing with cold." The design of Savery's lifting engine, reproduced in Fig. 305, as far as its essential arrangements are concerned, shows that the steam was produced in a separate vessel B (the boiler). The steam first filled the vessel S and the pipe A, out of which it drove the air; then closing the tap C, and opening the tap *e*, leading from a reservoir full of cold water, he produced condensation of the steam in the vessel S; a vacuum was formed, and the water of the reservoir R rose and partly filled the vessel and the pipe. A jet of steam coming then from the boiler and pressing on the surface of the liquid forced it to rise to a height depending on the pressure. A fresh condensation then took place, a fresh action of the steam, and so on indefinitely.

"To raise the water to the height of only 200 feet, for example, Savery was forced," says Arago, "to bring the steam of his boiler to a pressure of six atmospheres; hence there were continual disarrangements of the joints and melting of the solders as well as dangerous explosions; so that in spite of the title of his work, *The Miner's Friend*, his engines were of no use to the mines. They were only

employed to distribute the water to different parts of palaces or villas, in parks and in gardens, or anywhere, in a word, where the difference of level to be overcome was not greater than forty feet."

Savery's engine, we see, utilised the elastic force of the steam to drive back the water directly, and the condensation of the same steam to produce a vacuum, and cause the ascent of the water under the atmospheric pressure. It was a sort of suction and force pump, where the force of the steam took the place of the muscular energy applied to work the piston in the cylinder of these hydraulic apparatus. It

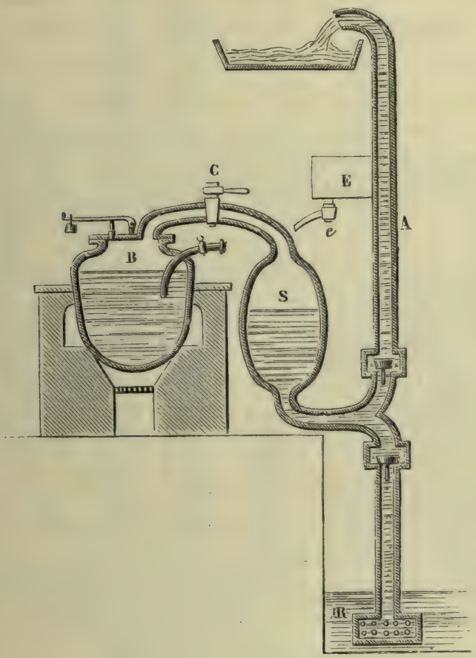


Fig. 305.—Savery's steam-engine

is not therefore at all comparable with the modern steam-engine, such as we know it.

Fourteen or fifteen years after Papin's attempt, Savery associated himself with two of his own countrymen, Thomas Newcomen and John Cawley, both living at Dartmouth in Devonshire, where one was a blacksmith or ironmonger and the other a glazier. From this association arose the steam-engine known as Newcomen's or the Atmospheric Engine.

We will shortly explain the mode of action of the steam in this engine. (Plate XV.)

The boiler furnished steam at a pressure a little above that of the atmosphere. At the moment it was set to work, and the piston was at the upper end of the cylinder, the steam filled the latter and drove the air out by an orifice called the snifting valve. Then the tap of a pipe is opened, and the cold water injected into the cylinder condenses the steam, and when the tap is closed, the outside pressure of the atmosphere works on the piston and drives it to the bottom of the cylinder.

At this moment a slide-valve opens the communication of the cylinder with the boiler, so that the steam below and the atmospheric pressure above the piston are balanced. The piston would remain then in this situation but for a counterpoise attached to the beam of the engine, which forces it up to the top of the cylinder: another condensation now makes it descend, and so on, and the two-and-fro motion is produced.

We see now the reason of the name, atmospheric engine, given to it, for it is the pressure of the external air that is the real motive force. The steam comes into use only to balance it during the ascent of the piston. During the descent the condensation of the steam produces a vacuum, and it is the pressure of the air again that makes the piston descend.

The atmospheric engines were chiefly employed as pumping engines for mines. They were also employed for distributing the water in London. Notwithstanding the immense improvements introduced during a century and a half, into engines which work by steam, Newcomen's engines appear to have been used for a long time in places where coal was cheap.

The steam-engine, with a few unimportant improvements of detail, remained in the state into which Newcomen, Savery, and Cawley brought it, until the year 1769. Sixty-four years thus passed away without fruit, as we may say, until the genius of Watt, seconded by the rapid progress of physical science in that half century, made of it the powerful motor, the incomparable engine which we have described in choosing the beam-engine which still bears the name of Watt for our type.

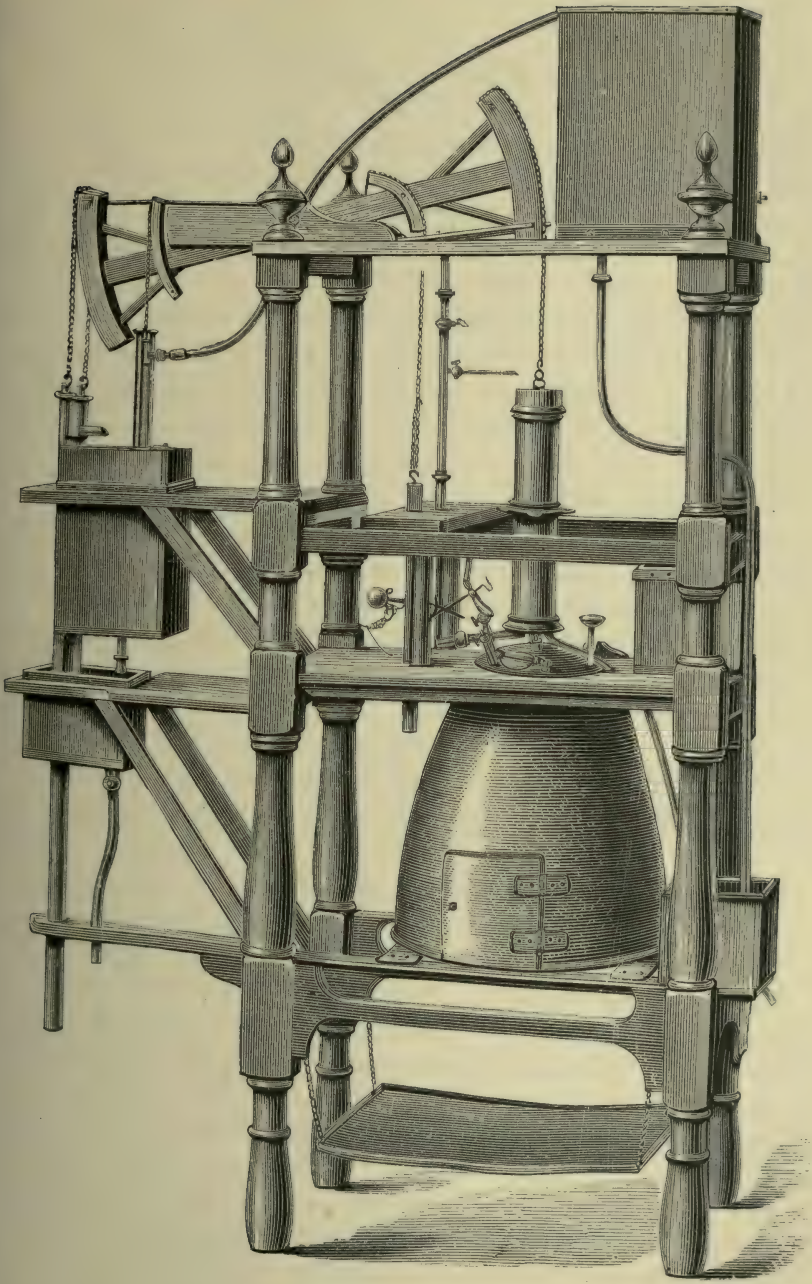


PLATE XV.—ORIGINAL MODEL OF NEWCOMEN'S ENGINE.
(In the Science Museum at South Kensington.)

§ VI.—Watt and the Steam-engine.

We have just seen that Newcomen's engines were simply pumps, of great value doubtless, for draining the water from mines, but not true prime movers capable of furnishing a regular and constant motion adapted to the requirements of every kind of manufacture. The reason of this is simple. The atmospheric pressure which produces the downward motion of the piston is the true motive force in these engines, which have no effective power during the upward motion: this was enough for working the pumps to which they were applied, but it was a serious drawback for a prime mover, which should have no intermittence of action.

The atmospheric engines were thus single-acting engines. Watt transformed them into double-acting machines. The cylinder, open at the top, was replaced by a cylinder closed at its two ends, and divided by the piston into two distinct chambers into which the steam alternately penetrates, and is then allowed to escape into the condenser.

Thus was created the true steam-engine in which the elastic fluid is the true motive power and sole cause of the motion. The oscillations of the piston then communicate oscillations of equal force, and of equal amplitude to the beam. In one word, with double action the steam-engine became a universal prime mover, applicable to all kinds of industry.

Besides this, by rendering the steam-engine capable of universal employment, Watt opened the door by this very means for all the subsequent improvements. He himself devoted all his powers and all his intelligence to this at first arduous task. By the invention of the *governor* he reduced still further the irregularities of the motion. "The efficacy of the governor is such," says Arago in his biographical notice of Watt, "that there might be seen some years ago in Manchester, in the cotton-spinning factory of a talented mechanician, Mr. Lee, a clock set in motion by the steam-engine of the establishment, and which went about as well as an ordinary spring clock beside it. Watt's governor, and a pretty free use of fly-wheels, are the true secret of the astonishing perfection of the industrial productions of our day; it is these that now enable the steam-engine to work entirely free from stoppages, and by these it is possible to embroider muslins

as successfully as to forge anchors, to weave the most delicate fabrics, and to communicate a rapid motion to the heavy millstones of a corn-mill. This also explains how Watt could say, without fear of the reproach of exaggeration, that in case of sickness, in order to avoid the coming and going of servants, he could carry up food to the patient by engines driven by steam."

The invention of the separate condenser, and of the pumps connected with it, was of capital importance, principally from an economical point of view. For an equal effect, it reduced the consumption of fuel to a quarter of that used in Newcomen's engine. The following fact, often quoted by the historians of the steam-engine, will give us an idea of the value of the economy immediately effected in mining countries where the pumping engines are worked, and afterwards in all the factories where steam, at low or medium pressure, is employed. Three pumps used to be at work in the Chasewater mine, whose proprietors paid Watt and his partner Bolton a royalty for the right of using the condenser. This royalty was fixed at one-third of the value of the coal saved. Now these proprietors thought it to their advantage to redeem these rights by an annual payment of 2,400*l.* Thus the addition of a Watt's condenser produced in each engine a saving of fuel worth more than 2,400*l.* per annum, or more than 7,200*l.* for the three engines in the mine in question.

The use of expansion, which Watt had made known, but which was not adopted on a large scale till after Woolff's invention of engines with two cylinders, has increased still more the economy of steam and consequently of fuel—the *desideratum* of all who have attempted to improve the steam-engine. At first only constant expansion was known, but now, fresh arrangements enable us to make the expansion variable.

We must not, in justice, in the history of the improvements of the steam-engine, mention only the name of Watt. Keane Fitzgerald (1758) was the first who used the fly-wheel to regulate the motion of rotation; and the employment of connecting rods and cranks for transforming the rectilinear oscillating motion of the pendulum into a rotatory motion is due to Washbrough (1778). Lastly, Murray (1801) was the inventor of the slide-valve worked by the excentric. For the rest, I shall complete as far as possible this short history of the progress of the steam-engine by describing marine engines, locomotives and portable engines.

CHAPTER VIII.

STEAM NAVIGATION.

§ I.—Marine Engines.

ONE hundred and two years elapsed between the first actual industrial application of the steam-engine and the definite fixing of one in a ship of which it was to be the mover—between Newcomen and Fulton.

Yet neither the original idea nor attempts at carrying it out were wanting.

We must go back to Papin again for the first clear statement of the idea of this application which was destined to have, a century later, so considerable a development. In 1695,[1] he pointed out the possibility of applying the force of steam "for rowing against the wind;" and remarked "how far preferable this force would be to that of galley slaves for quick motion on the sea;" and he proposed to substitute "turning oars" for ordinary oars; and he puzzled himself to find some machinery for obtaining a continuous motion of rotation.

More than this, it appears established that in 1707, Papin had put this idea, which he had only indicated before, into execution, and that he had a steam-engine actually constructed and placed in the vessel it was intended to move. He embarked at Cassel, on the river Fulda, and, after having reached Münden (Hanover), he proposed to continue his journey by the Weser as far as Great Britain, when the watermen of the river, rising against the great man and this invention that seemed to menace their craft, broke the boat and the engine to pieces.

[1] Collection printed at Cassel. An extract from the *Acta Eruditorum* of Leipzig.

In 1737, an Englishman, J. Hull, proposed to replace the oars by two paddle-wheels behind the vessel, and to turn their common axis by a Newcomen's engine. This project was never put into execution.

The first experiment of steam navigation, after Papin's, was made at Paris, on the Seine, opposite the Champ de Mars. The boat had been built by the Count of Auxiron. A year afterwards, 1775, Perier, who was made a member of the Academy, made similar experiments with no better success.

Fresh attempts, with increasing success, followed one another to the end of the century. In 1778, the Marquis of Jouffroy tried a steamboat at Baume les Dames, on the Doubs, and, three years later, at Lyons, on the Saône. In this last attempt, which was reported very favourably, he used a boat forty-six metres long and four and a half metres broad. An atmospheric steam-engine at first communicated motion to two things like shutters, which opened and closed alternately, but which were afterwards replaced by two paddle-wheels.

We must further mention, among those who have contributed to realize Papin's idea and invention, Patrick Miller of Dalswinton, Scotland, who published at Edinburgh (1787) a work on the substitution of paddle-wheels for oars, and on the possibility of employing the steam-engine to move them.

For some years prior to 1787 he had been engaged in a series of experiments with double and triple vessels propelled by paddle-wheels, worked by manual labour. In the experimental trips of 1786 and 1787 he was assisted by Mr. James Taylor, and at the suggestion of the latter it was determined to substitute steam power for manual labour. For this purpose, in the early part of 1788, Taylor introduced William Symington, an engineer at Wanlockhead Lead Mines, who had previously obtained letters patent (June 5, 1787, No. 1,610) for "his new invented steam-engine on principles 'entirely new.'"

An arrangement was made with Symington to apply an engine, constructed according to his invention, to one of Mr. Miller's vessels, and the engine was made, the castings being executed in brass by George Watt, founder, of Low Calton, Edinburgh, in 1788. At the beginning of October in that year the engine, mounted in a frame, was placed upon the deck of a double pleasure boat, 25ft. long by 7ft., and connected with two paddle-wheels, one forward and the other abaft the engine, in the space between the two hulls of the

double boat. On the steam being put in action it propelled the vessel along Dalswinton Lake at the rate of five miles an hour.

The Abbé Darnal in France (1781), the Americans Rumsay and Fish (1786-1788), Lord Stanhope (1795), Baldwin (1796), Livingstone (1798), Desblancs, Smington, Stevins, Oliver Evans, all made attempts to navigate by steam—attempts which continued to increase both in Europe and America, until the time of Fulton, the American, who at last obtained complete success.

In 1802 and 1803, Fulton studied in France the practical conditions of the problem to be solved, and he was seconded in his endeavours by his compatriot Livingstone, at that time United States Ambassador. A boat constructed on the Seine gave a velocity of 1·60 metres per second.

Fulton made propositions to the French government which were not accepted, and their rejection decided him to return to America. He had constructed and sent to him by Bolton and Watt a steam-engine which when placed on the ship *Clermont*, in August, 1807, furnished at last the definite and practical solution of the problem of steam navigation. The voyage from New York to Albany, a distance of 180 miles was at first accomplished in thirty-two hours, then in thirty hours, and a regular service was not long in being established between the two towns. Steam navigation had passed from the state of outline to that of an accomplished fact—from the period of attempts and experiments to that of success and triumph. Seventy years have passed since then.

In August 1812, the steam passage boat *Comet*, built on the Clyde by J. Wood for Mr. Henry Bell, at Port Glasgow, in 1811, the first steam vessel ever built in Europe, began to run between Glasgow, Greenock, and Helensburgh, with passengers only. She was advertised to leave the Broomielaw on Tuesdays, Thursdays, and Saturdays, at an hour suitable to the tide, and to return from Greenock on Mondays, Wednesdays, and Fridays. The fares were 4*s*. for the best cabin, and 3*s*. for the second, and no gratuities to the vessel's servants were allowed. The boat was driven by a condensing steam-engine of four horse-power. She had at first two sets of paddle-wheels on each side of the vessel. Her greatest speed was five miles per hour. Her dimensions were as follows:—Length 42ft., breadth 11ft., depth 5ft. 6ins.

Great is the interval to-day between Fulton's and Bell's steamers and the grand transatlantic steamships which regularly cross from the old to the new world. The progress of steam navigation in the last sixty-five years has been immense, but we must not forget the share which belongs to each of those inventors who without being discouraged have worked for this end, from the modest Papin up to Fulton and Bell.

§ II.—Paddle Steamers.

When the power of steam was discovered, the idea had long been conceived and even tried of replacing the oars by wheels to be turned by the muscular action of men or animals. The Romans and Carthaginians had long before used boats which were moved by paddle-wheels, ancient medals represented the *liburnæ* (the ships employed by the Romans at Actium) with three oars of paddle-wheels along the sides turned by three pairs of bullocks. We read that[1] "in China, where they have been used from time immemorial, are to be seen junks with four wheels, moved by an ingenious crank worked by men." In 1472, Valturius de Rimini described a wheel the shaft of which was moved by men by means of bent cranks, and in which paddles replaced oars. A similar propeller was proposed in 1699, by Du Quet to the Academy of Sciences in Paris. When Papin, a few years earlier, proposed to apply steam to ships, he mentioned the rowing wheel of Prince Palatine Rupert's sloop, which he had seen in England in 1678. These wheels were moved by horses yoked to a beam.

This method of propulsion could not be seriously adopted till after the discovery and application of a powerful motor, and we have just seen that this motor is steam. It is only therefore since Fulton's and Bell's time that rivers, lakes, and seas, have been furrowed by ships and boats provided with paddle-wheels—that is, the well-known arrangement by which a kind of water-wheel on each side the ship is set in motion.

The paddle-boards, which radiate all round the axis, and are

[1] *Bibliothèque des Merveilles.*

solidly attached to it by iron rods and fellies (see further on, Fig. 311,) are rectangular plates, which when set in motion by the rotation of the driving shaft, successively plunge into the water, and pressing against it push forward the boat in the direction opposite to that of their own motion. The wheels are always two in number, for the sake of symmetry and equilibrium; they are mounted on the same axis or shaft which crosses the ship perpendicularly to its length, and when they are immersed vertically in the water, their upper border ought to be covered to a height of ·10 to ·20 metres.

The mechanical work of paddles on the water resembles that of oars. They produce no useful effect in pushing the boat forward except by pushing the water backward. This last motion, without which the first, which is the reaction from it, would not exist, is called the recoil. It absorbs a considerable quantity of the work of the steam independently of the losses occasioned by friction. As an example of this division of moving work, we will quote the words of M. Sonnet, as the result of experiments made on the steamboat *Castor* working between Honfleur and Havre. "Of 100 horse-power furnished by the engine 33·9 are employed to overcome the resistance of the water on the ship, which constitutes the useful work; 58·2 are consumed by the recoil, that is to say, to put the water in motion; friction uses up only 7·9."

The successive blows of the paddles on the water at their entrance and exit produce a series of troublesome and fatiguing tremblings in the ship which is much diminished by giving a slight inclination to the paddle-boards in the direction of their length. One extremity then enters after the other, or, if desired, the immersion may be continuous over the whole length of the paddle-board. By this means the blows and the tremblings resulting from them are almost insensible.

On waters with a calm surface, where the ships can preserve a nearly horizontal position of equilibrium, paddle-wheels do excellent service. But it is not the same on the sea, where the action of the rollers makes the ship incline to the right or left, and this inclination prevents the axis of the wheels from remaining horizontal. The two wheels are then immersed unequally in the water and their action on the water and their propelling motion becomes unequal. The result is a dangerous deviation in the course of the ship as well as a loss of

force and velocity. We speak here of the principal disadvantage of paddles which affects the progress of ships of all sorts. But in ships of war they have a still greater drawback ; they reduce the offensive power by taking up the room from the guns ; they reduce the defensive power by exposing the propeller itself to the fire of the enemy.

The result has been that the transformation of the navy from sailing to steamships was retarded, till a new propeller was invented which was not subject to either of the two disadvantages we have just mentioned, and which thus rendered possible a wide application of steam power to ships of war. This new propeller is the *screw*, which, like the paddle-wheels, steam itself, and many other mechanical and physical inventions, &c., has been the object of a pretty numerous series of trials and attempts before the true and decisive mark of success, that of industrial or practical realization, was obtained.

Although the system has not been extensively introduced, Ruthven's hydraulic propeller must be mentioned. In this the steam-engine is used to eject two jets of water at high velocity, from nozzles at the ship's side. From trials made by the Admiralty with the *Waterwitch*, this mode of propulsion held its own with the screw. The nozzles turn in collars fitted to the ship's side, and can be pointed ahead or astern.

§ III.—Screw Steamers.

The screw is nothing else than an ordinary male-screw or fragment of one, which, forming part of the ship, advances through the water and propels the ship, forming the movable female-screw in the water itself. The motion of rotation of the screw about the axis of the propeller is produced by a steam-engine on board the ship.

All that has been said on the propulsive actions of paddle-wheels is applicable to the screw. Here also, by pressing on the movable mass of water, and impressing on it a motion in a direction contrary to that of the ship, the motion of the latter is produced. It is thus inevitable that a considerable fraction of the moving force should disappear as a pure loss. The advantages of the screw as compared with paddle-wheels are of another kind, which we will shortly mention.

The screw is placed behind the ship, in a rectangular framework which opens near the stern-post. The axis or driving shaft which supports it is parallel to the keel. It rests at the front end against the buttress, a sort of block solidly fixed in the hold, and behind it passes through the hull by a stuffing box. The engine sets this shaft and the screw in motion either directly by cranks and knee-joints, or indirectly by wheel-gearing.

This propeller is always immersed, and at such a depth that the disturbing motions of the sea have no action upon it. It is not therefore subject like the paddle-wheels to inequalities of action. In addition to this, the screw is almost entirely protected from shot—and so are the engines required to move it, since they are fixed like the screw below the water-line. Lastly — a consideration of the highest interest for steamships of war—the fighting decks are not in the least obstructed by them.

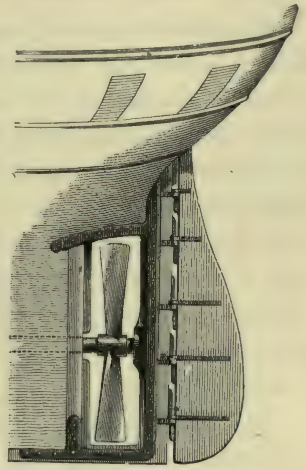


FIG. 306. -Framework of screw behind a ship.

In general, the screw has this further advantage over paddles, that it leaves the ship quite free for working the sails—so that screw-steamers may be rigged to take advantage of the wind when it is favourable, which is a great advantage from an economical point of view, ships with sails and paddle-boxes are, on the contrary, difficult to manage.

We will pass in review as briefly as may be the history of the invention of the screw and its application to steam navigation.

As in the case of the paddle-wheels, the first attempt was to move the screw by living forces, either of men or animals. Duquest (1727) availed himself of the currents of rivers for rowing boats, by using Archimedes' screw. Paucton (1768) employed a helicoid of four branches which he turned by the hand.

In 1803, the engineer Dallery took out a patent for the propeller moved by steam and composed of two screws—one with a movable axis, placed in front, serving for rudder, and the other placed behind,

adding its impulse to that of the former—and in this way the ship was moved. The names of Shorter (1802), Samuel Brown (1825), the clever French Captain Delisle (1823), the brothers Bourdon and Savage (1832), should be quoted in the list of those who have conceived plans or made attempts towards the application of the screw to propelling ships.

Two men—an English mechanic, Smith, formerly a simple farmer, and the Swedish engineer, Ericson—may be considered as having definitely and almost simultaneously solved the problem.

The *Archimedes*, a steamship of 90 horse-power, was the first vessel which was driven by the action of one of Smith's screw-propellers in 1838. Four years later the *Princeton* of 220 horse-power, provided with an Ericson's screw was launched in the United States.

The first attempts of the Swede Ericson were made in England. A ship called the *Francis B. Ogden*, provided with his propeller, towed a schooner of 140 tons burden, at the rate of seven miles an hour. But Ericson having received no encouragement in England went to the United States, where his invention was received with the enthusiasm it deserved. He had allied himself before his departure with Stockton, a naval officer of the United States, and it was on the *Robert Stockton*, a screw steamer of seventy horse-power, that they crossed the ocean together, and disembarked on the coasts of the great Republic. The *Princeton* soon followed this first English constructed boat.

In 1842, France followed the example set by the two great maritime powers. A ship of 130 horse-power provided with an Ericson screw was constructed at Havre.

Since that time the transformation of fleets into screw steamships has made great progress in the world. Merchant vessels and packets followed the example, without the system of paddle-wheel propellers, which also has its advantages, being altogether abandoned. This is not the place to give the history of these changes; we return, therefore, to the description of the different screws adopted, and then take up again that of marine steam-engines which are more particularly our study.

Smith's first screws were formed of a whole turn round the axis; later he reduced the screw to a half turn, but doubled it (Fig. 307). Experience soon showed that the extension of the spire in the

direction of the axis might and ought to be considerably reduced. Much smaller fractions were then employed, and the branches or wings of the propeller were multiplied, though they were often no more than four and sometimes two in number (Fig. 308). The employment of screws with six blades or more, offers more disadvantages than advantages, for the action of one would interfere with that of another.

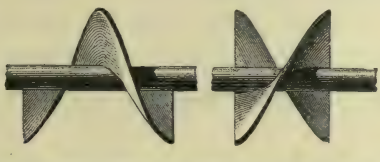


FIG. 307.—Smith's first model screws: single screw with complete turn; double screw with half turn.

It is the extension of the diameter of the blades of the screw and the rapidity of rotation that gives most power to the propeller.

We have stated how the screw is arranged in its frame behind a ship. We should add that to avoid the resistance which would be offered by the screw in the case of sailing being substituted for steam, arrangements are made either to make it loose, or to take it for a time

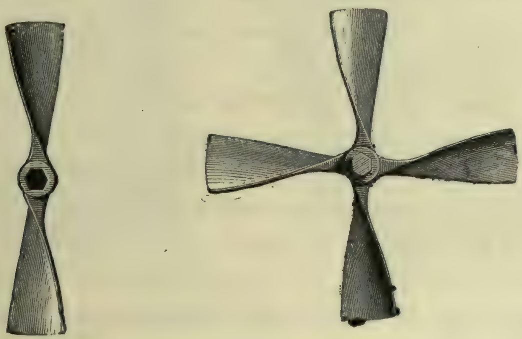


FIG. 308.—Screws with two and four wings.

out of its frame. In the latter case a well is formed in the hinder part of the vessel, the screw is taken off, and raised between sliding boards into the well where it can also be examined and repaired according to requirements.

In Griffith's screw propeller—probably the best modification of the common screw now in use—a hollow sphere is substituted for the central position of the blades, which in the ordinary form absorbs

20 per cent. of the propelling power, without giving any useful effect, as the blade is then nearly in a line with the shaft.

Several experiments have been made lately with twin screws, arranged one on each side of the keel, instead of a single one in the axis of the vessel. Great facility is afforded by this arrangement for turning and steering with or without a rudder, but so far as speed is concerned, no advantage is gained.

§ IV.—Marine Boilers and Engines.

We are now acquainted with the propellers for steamships, and we must next inquire how steam, the only motive force sufficiently powerful to fall back upon as a substitute for the inconstant and often contrary force of the wind, gives to the wheels or the screw their rotatory motion.

Is the steam-engine, such as we have described it, modified in any essential particulars when it becomes a marine engine ?

No. In reality, not only is the principle identical, but the chief parts—the generator, the driving and transmitting machinery remain the same. They have only, as we shall see, to submit to the particular necessities of being placed in a ship.

At first, low-pressure engines with condensation—that is to say, Watt's beam engines—which were the only ones elsewhere employed in industry—formed the type of navigating engines, whether on rivers, lakes, or seas; and paddle-boats still use them with advantage. Their motion is comparatively slow, but as is well known, this slowness is largely compensated for by the regularity of their working. They are unwieldy and cumbersome certainly, but all their parts are easily accessible for inspection, maintenance, and, when needed, for repairs. These engines were adopted in the navies of England and France before the invention of the screw had changed the conditions of the problem. For working the screw, these engines give too slow a motion of rotation—which would no doubt be easy to multiply by cog-wheels, but at the expense of the effective force of the engines, in other words, of their available work.

Condensation is generally adopted not only where it is necessary, that is to say in low-pressure engines, but also in marine engines

at mean and high pressure. The abundance of water renders the employment of condensers easy and economical.

The steam-engines employed in navigation are the most powerful constructed. It is not rare for their effective force to be measured by hundreds of horse-power. In some ships of the navy horse-power is indeed counted by thousands. We must add that the estimation of the power of the engines in horse-power—what is called their nominal force—is made differently for these and for land-engines. The *low-pressure horse-power,* or *nominal horse-power,* in shipping, means not 33,000 only, but more than 44,000 foot-pounds,

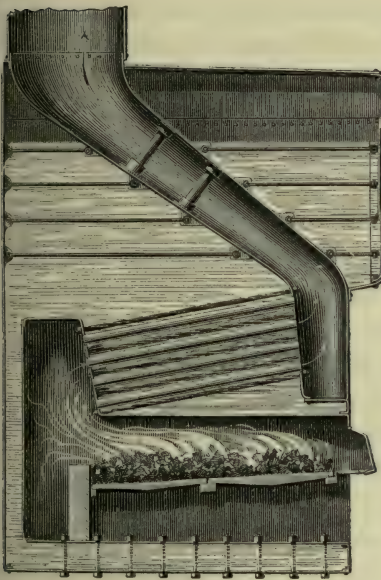


FIG. 309.—Tubular boiler, with return flame, of the *Isly:* section.

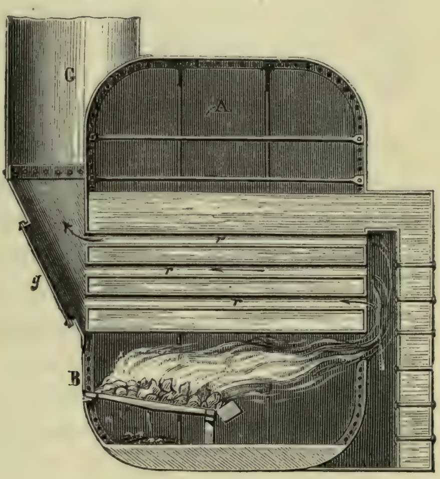


FIG. 310.—Marine tubular boiler with return flame: section.

the mean being 47,000 on the shaft and 59,400 on the pistons. The reason of this is that the loss of motive power in the recoil has forced constructors to exaggerate the force in view of the useful effect to be produced. Even the numbers we have just given are now too small; in the United States shipping the horse-power *nominal* reaches 182,000 foot pounds.

At this rate the steam frigate *Friedland,* whose engines have an

effective power of 4,000 horses at 33,000 foot-pounds, ought to be reckoned to have only 1,000 horse-power *nominal.*

To obtain such power it is necessary to employ generators that are capable of vaporizing considerable weights of water, and having therefore large heating surfaces.

Tubular boilers are generally employed, of which Figs. 309 and 310 represent types. Besides this, a single boiler and a single furnace are not considered enough,—the *Warrior,* for instance, has 10 boilers and 46 furnaces on board.

The amount of fuel consumed is something enormous. We will quote a few figures.

The *Great Eastern,* the largest vessel afloat, the gross tonnage of which is 22,500 tons, is furnished both with screw and paddles. The engines of the former are 1,600 horse-power nominal, of the latter 1,000 horse-power nominal. Her average consumption of coal a day is 270 tons; with this consumption her paddles revolve 13,000 times and her screw 52,500 times a day.

The French armour-plated frigate *Friedland,* which, with its complete freight of coal and munitions weighs 7,200 tons, consumes at full speed about five tons of coal an hour, or 125 tons every day she continues to travel. This is an expense which varies according to the price of coal from £160 to £200 a day for the fuel alone.

The external appearance of marine boilers and engines is not very like that of the steam-engines employed in manufactories. Although all their parts are of relatively large size, they are arranged so as to occupy the smallest possible space. Boilers, condensers, driving machinery, &c., all are set close together.

The chief special types of Marine Engines are as follows :—

Trunk-engine.—In this engine there is a hollow cylinder fastened to the piston itself, and working steam-tight through the cylinder cover. At the bottom of the hollow cylinder the connecting rod is made fast, the hollow cylinder being large enough for its vibrations, thus doing away with all the parallel motion and piston-rod. Sometimes the hollow cylinder is made to pass through both ends of the large cylinder, to equalise the pressure.

Side-lever Engine.—The side-lever engine is an engine something after the fashion of the beam-engine, but having the beam about the level of the bottom of the cylinder, and the top of the piston-rod

made fast to it by means of a cross-head brought down by side pieces. At the other end of the beam there is a connecting-rod to the crank. In this form, the rod connecting the crank and the end of the beam may be longer; the power is thus delivered to the crank more equally, and the weights of the moving parts are balanced, so that a slight pressure of steam is able to drive the engine both ahead and astern, the parts being in equilibrium. But there is an objection to this kind of engine, the parts are heavy and not compact, these qualities being most detrimental in a war-steamer.

Oscillating Engine.—This engine has derived most of its elegance and perfection from Mr. Penn. The name of the engine is derived from the fact that the cylinders oscillate upon hollow axes or "trunnions," through which the steam is admitted and withdrawn from the valves; the piston-rod connects itself to the crank without the use of any extra gearing; in fact this is one of the most direct-acting engines known, and is used in the largest ocean as well as the smallest river steamers, in the latter of which it was first tried by Maudsley.

Annular Engine.—In this variety of engine the cylinder is made in the form of a ring with a central cylinder. There are two piston-rods made fast to a cross-head in the form of a T, the tail of which works in the central cylinder between sliding faces, the connecting-rod being fastened at the end of the tail, which transmits the power to the crank. This kind of engine allows a long connecting-rod and therefore the paddle-shaft high.

Fig. 311 represents a side-lever engine. The beam oscillates below the cylinder and piston—an arrangement rendered necessary by the situation of the driving shaft, or the axis of the paddles, which necessarily occupies an elevated position in paddle-ships. The connecting-rods are joined immediately to the shaft, which is bent at two points so as to form two cranks at a right angle, each working with one cylinder. The cylinders are vertical. When the same type of machines is applied to the screw the cylinders are placed horizontally across the ship. Sometimes direct horizontal machines with two cylinders are preferred, and then the connecting-rods work on a crank on the shaft of the screw itself.

The cylinders of marine engines are often of colossal dimensions. Those of the *Great Eastern* are 7 feet in diameter, with a 4 foot

stroke. In the *Minotaur* the cylinders are 9 feet 4 inches in diameter, with a 4 feet 4 inch stroke. The cylinders of the *Friedland* engines have an interior diameter of 2·10 metres, and the stroke of their pistons is not less than 1·30 metres. The pressure of the steam is thus exerted for each piston on a surface of about 3·50 square metres; if we suppose the tension of the steam to be two-and-a-half atmospheres, this pressure is equal to 90,000 kilogrammes. To guide pistons of such dimensions, not one only but two or four rods are employed, which articulate by a transverse with the connecting-rod.

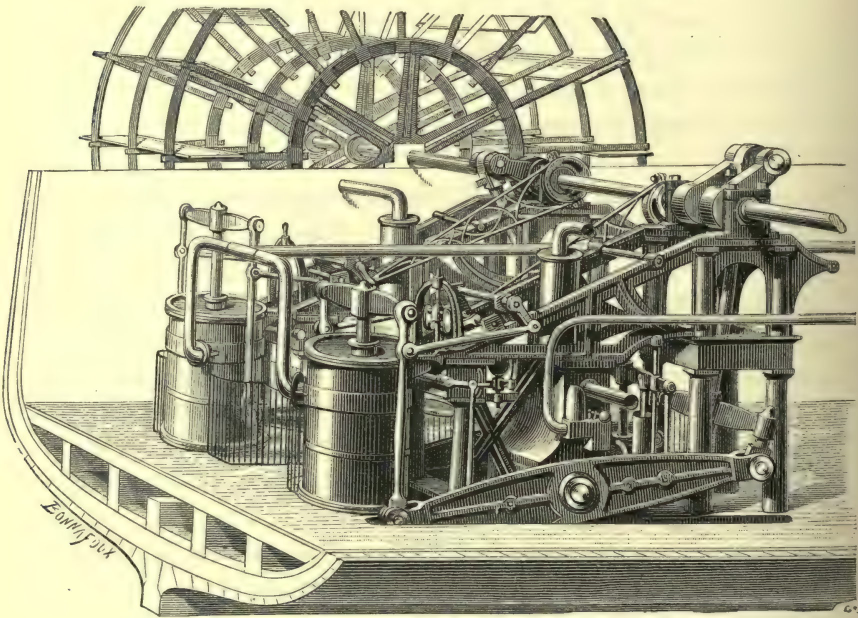


FIG. 311.—Side-lever engine of the *Sphynx.*

The latter returns upon itself to articulate with the knee of the driving-shaft, performing the function of the crank, and for that reason it is called the return connecting-rod.

The engine of the *Friedland* is remarkable not only for its dimensions, its power, and the speed it gives to the ship, which in calm weather is not less than fourteen and a half knots an hour, that is about seventeen and a half miles. Its screw is 6·10 metres in diameter; it was to be seen in motion in the Paris Exhibition of 1867, and any one placing himself in the direction of the motion of

the blades of its screw felt the sensation of a current of air produced by the motion of its enormous whirls. This engine is also remarkable as a type with special qualities, on which we will say a few words in conclusion. It is an expansion engine on Woolff's system, with this peculiar arrangement, that it comprises three equal cylinders of the same diameter and the same height. The steam is at first introduced into one cylinder only, the middle one; after having worked at full pressure in this, it then enters the two lateral cylinders, where it expands, and passes thence into two separate condensers. On leaving the boiler, the steam circulates in a drying apparatus, and

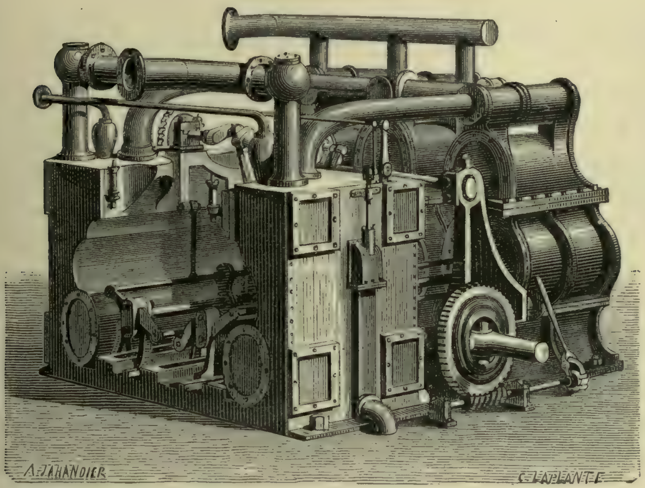


FIG. 312.—Combined engines of the *Friedland*.

then bifurcates into the steam jackets of the extreme cylinders. For equal power and equal weight of engines a remarkable economy of fuel is obtained with this system, as compared with the double cylinder system. The knees or cranks of the driving shaft, which receive the heads of the connecting-rods are arranged at right angles in the corresponding knees of the two outside pistons, and in the bisector of that angle produced in the case of the middle knee, the advantage results, that all the movable pieces keep very nearly the same position of equilibrium about the axis of the shaft, whatsoever may be the position of the ship as determined by rolling.

The trunk engines and oscillating engines, which have been described in the paragraphs relating to transmitting machinery, are often employed in steam navigation, whether on rivers or at sea. I think I have already said that the first are chiefly used in the English marine. In general the differences to be met with between the fixed land engines and the marine are almost all due to modifications rendered necessary by the question of space and position.

CHAPTER IX.

THE LOCOMOTIVE.

§ I.—STEAM ON THE RAILWAYS.—THE FIRST LOCOMOTIVES.

THE parent of the locomotive is the steam carriage. The first attempts at carriages moved by steam date from the time of a French engineer, Cugnot, who in 1769 invented and constructed at Paris a carriage which was intended to be moved by steam along the ordinary roads. After him came Oliver Evans, who, in Philadelphia in 1804, constructed the first carriage of this kind that was seen in America.

Locomotion on roads by means of steam could not succeed or obtain the immense extension it now possesses but for the adoption of a new kind of roadway. This was at first applied to the transport of materials at coal mines. Thus we find in the year 1745 cast-iron rails fixed on sleepers forming a mineral railway from Tranent to Cockenzie in Scotland. At present there was no flange: this was added afterwards. To Richard Trevethick belongs the merit of inventing a self-acting steam-carriage to travel with flanged wheels on rails. This was at work on the Merthyr Tydvil Railway in 1804. This locomotive was capable of drawing ten tons at a rate of five miles an hour. Progress at this time was much impeded by the idea that great speed could never be attained by smooth wheels on smooth rails, or that a load could be drawn up an incline. Several means of overcoming this practical difficulty were suggested,[1] when an

[1] For example, the employment of a toothed wheel working into a rack placed between the rails, or movable jambs, which were alternately pressed against the ground and then raised.

English engineer, Blackett (1813), proved that the adherence of the locomotive to the rails could be secured. To this period belongs "Puffing Billy" (Plate XVI.), in which the axle-trees were kept working together by means of an endless chain. The adherence of all the wheels of the locomotive was thus secured.

The "Puffing Billy," the oldest locomotive engine in existence, and the first which ran with a smooth wheel on a smooth rail, was constructed in 1813 by Jonathan Foster, under William Hedley's patent, for Christopher Blackett, Esq., the proprietor of the Wylam Collieries near Newcastle-upon-Tyne. This engine, after many trials and alterations, commenced regular working in 1813, and with tender and two trucks, a total load amounting to fifty tons, ran at an average rate of six miles an hour. It was kept at work until the 6th June, 1862, and was then purchased for the Patent Museum.

It may be said that from this moment locomotion on iron rails by means of carriages moved by steam was a problem practically solved. Nevertheless, the locomotive did not as yet give a satisfactory result; the quantity of steam that the boiler could furnish was insufficient for the work or the velocity that was to be obtained. The reason of this lay in the nature of the boiler, the water in which was heated by a fire within a tube which traversed its whole length. The heating surface was not large enough for the vaporization required, and the draught was altogether insufficient.

In the years 1814 to 1820, thanks to the combination of George Stephenson, William James, and Edward Pease, the importance of improving the locomotive was clearly seen. Stephenson was employed on the Killingworth Railway in 1814, and often saw "Puffing Billy" at work. An Act of Parliament was obtained for a passenger railway between Stockton and Darlington in 1821, and James endeavoured, without success, to establish a railway between Liverpool and Manchester in 1822. By 1829 the locomotive had arrived at the form shown in Fig. 313, which represents the locomotive engine "Rocket," constructed by Stephenson, to compete with other engines on the Liverpool and Manchester Railway, where it gained the prize of £500. The Liverpool and Manchester Railway was formally opened for passenger traffic on the 15th September, 1830.

The locomotives of Stephenson and Hackworth in many respects realized improvements which had their importance. The driving

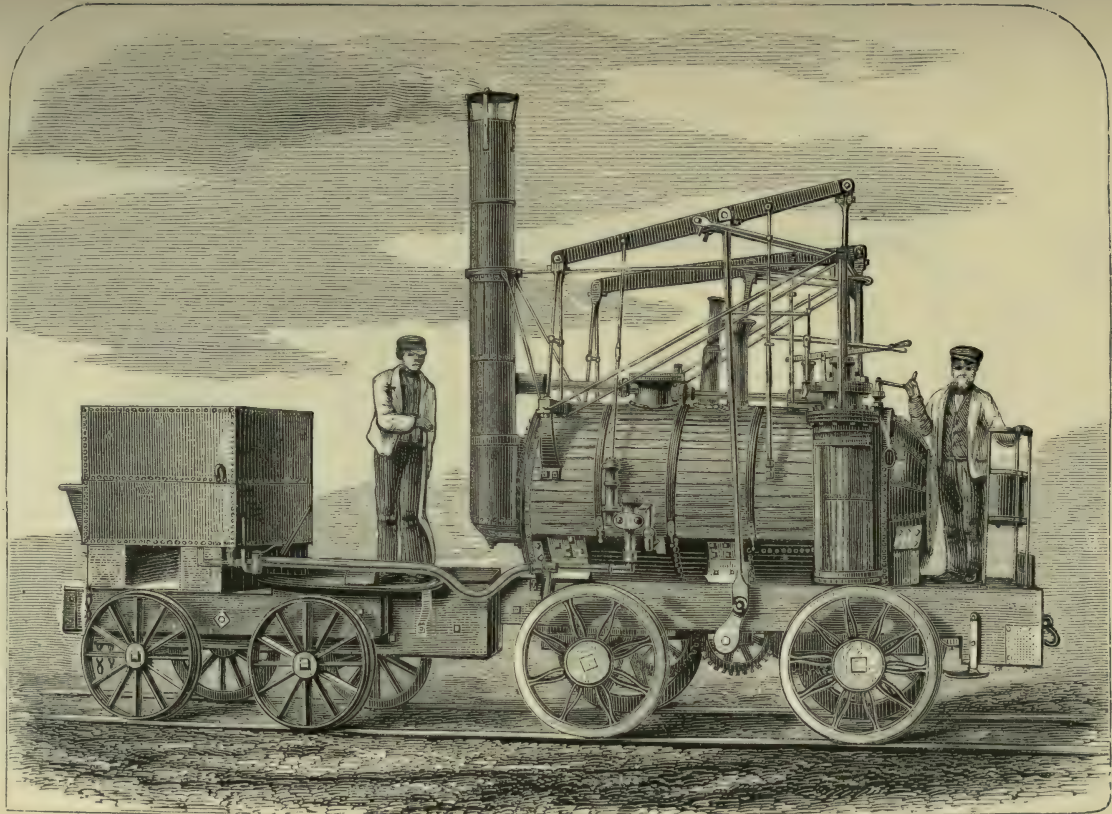


PLATE XVI.—"PUFFING BILLY."

and transmitting machinery, the adhesion of the wheels to the rails were the objects of arrangements it would take too long to describe. The substitution of the tubular for the ordinary boiler, with a draught

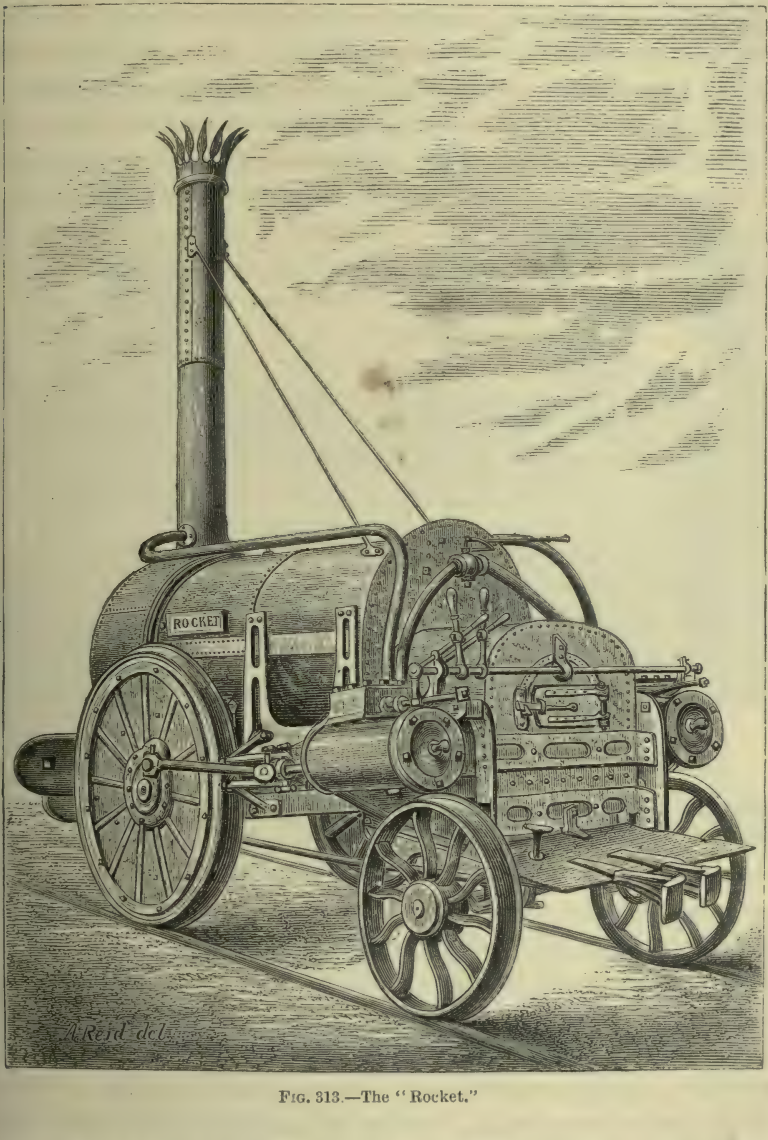


FIG. 313.—The "Rocket."

produced by a jet of steam, produced a decided revolution in the application of steam-engines to locomotion on iron ways. The invention

of tubular boilers is due to Mark Seguin. Owing to the enormous increase of heating surface which this arrangement affords, without augmenting the dimensions of the generator, vaporization is increased and the power of the engines is multiplied in proportion; but in order that so large a production of steam may take place, the activity of the fire must be kept up by an energetic draught, which the small height of the chimneys in a locomotive cannot give. It was therefore an equally happy discovery to make use of the steam when it had acted on the piston, and let it escape in the chimney itself, giving us what is termed the "steam blast," that is, a rapid current at each motion of the piston, which draws the air and gases of combustion through the tubes, and thus forms a draught in the body of the fire. Hackworth, Pelletier, and G. Stephenson are considered to be the inventors of this important improvement, which gave all its value to the tubular boiler in locomotives.

§ II.—THE MODERN LOCOMOTIVE.

Let us now see what the locomotive has become after forty years of incessant improvements.

Figs. 314, 315 and 316 represent a longitudinal section and two transverse sections in the front and at the back of the engine, and they will explain its principal arrangements.

And first about the steam-generator.

The boiler of a locomotive is tubular. It is composed of two principal parts: one, situated behind, and of rectangular form, incloses the fire, which is surrounded on all sides except the under one with water; the other, the *cylindrical body*, so named from the form of its covering, contains two distinct chambers. In the lower half are placed the tubes by which the smoke and gases of combustion pass from the fire to the chimney. All the tubes, often in considerable number, are surrounded by the water in the cylindrical body. The upper half of the cylindrical body is the steam space, which by a pipe bent forwards and backwards (*p s s u*, Fig. 314), opens at one end in the steam dome, and at the other in the steam-chest of each of the two cylinders of the engine.

The driver can open or close at will, by means of the handle *r*,

the valves of a diaphragm, *q*, which gives passage to the steam, stops it or introduces it, in greater or less quantity into the pistons; this is called the regulator, and on account of its form, the butterfly-valve.

On the convex surface of the cylindrical body are seen the accessory apparatus—safety-valves, pressure-gauge, water-gauge, and steam-whistle.

What is the distinctive characteristic of the boiler of a locomotive? It is, undoubtedly, the enormous extent of the heating surface relatively to the whole capacity. To show in what proportion this

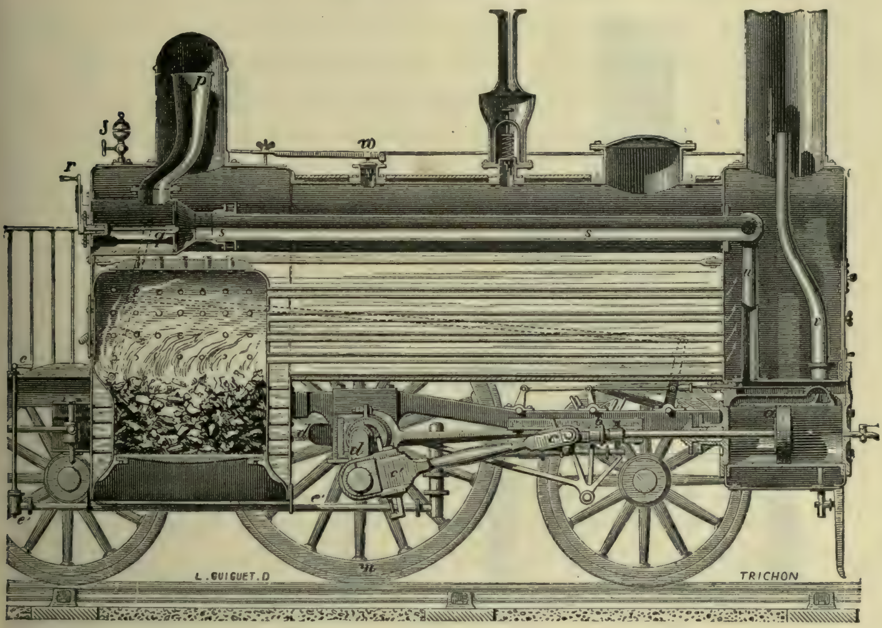


FIG. 314.—Locomotive: longitudinal section.

element is increased by the adoption of the tubes, we may quote some numbers. In a Crampton's locomotive the coverings of the fire, that is, the surface for heating by radiation, is but 8·65 square metres, the surface for heating by contact, that is to say that of the tubes that take up the gases of combustion, is 88·92 square metres, that is, more than ten times as great. In an English goods traffic engine the numbers are respectively 9·70 m. and 180·70 m.; the tubes augment the heating surface in the ratio of 1 : 18·6. Whence, we repeat, the importance of the steam blast, without which the activity

of the fire could not suffice for so considerable a production of steam, and without which consequently the tubular boiler in the locomotive would lose its principal advantage. In locomotive engines, says M. Perdonnet, each square metre of heating surface produces from two to three times as much steam as in the boilers of fixed engines.

Locomotives are high-pressure engines without condensation. This is a necessary consequence of the following circumstances. The steam must escape into the air, therefore, it cannot be a low-pressure engine; in escaping it must produce the blast, therefore it

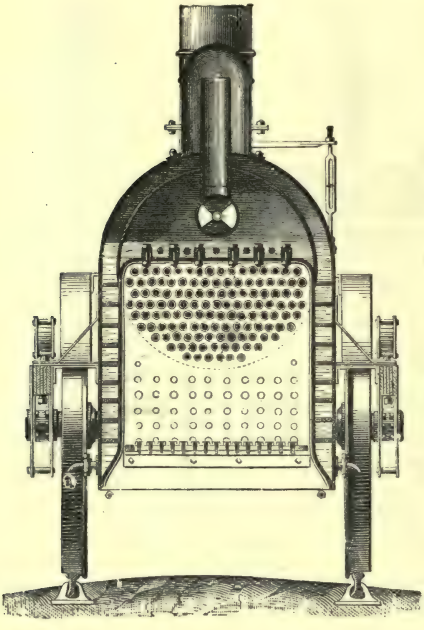


FIG. 315.—Locomotive: transverse section across the fire-box.

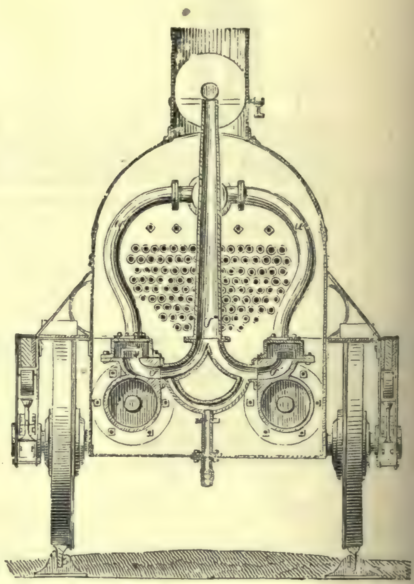


FIG. 316.—Locomotive: transverse section across the smoke-box.

cannot be condensed. It is generally employed at a pressure of eight or nine atmospheres.

But it works with expansion, and a peculiar mechanism, the *link-motion* of Stephenson, allows the expansion to be varied, and at the same time renders possible a change in the direction of the motion. A locomotive, like a steamboat (and the necessity of such an arrangement is obvious), can be made to go backwards as well as forwards.

The locomotive is in reality, so far as regards the driving machinery, formed of two steam-engines coupled together. There are two cylinders, each provided with its piston and its slide-valve, and each piston-rod acts, by a connecting-rod, on the crank or knee of the axle which carries the pair of driving-wheels. There are even in some kinds of locomotives four cylinders and four engines, working two by two, on two different axles. There is nothing special, except in the working and the details, to distinguish the driving-machinery from that we have seen at work in fixed engines, whether on land or sea. The drawings given show the arrangement of the cylinders, which are generally placed in front, sometimes horizontal, sometimes slightly inclined, sometimes placed outside the framework containing the boiler and engine, sometimes inside. In the figure the cylinders are inside and horizontal. This is the arrangement generally preferred in England.

Our longitudinal and transverse sections of a locomotive show its arrangements clearly. In Fig. 314 the distribution and escape of the steam are shown. The steam, which is brought by the pipe *ss* as far as the space called the smoke-box, finds there two conduits, *uu*, which end, after making a turn, in the steam-chests of the two cylinders; after having acted on the pistons, it crosses the pipes *v v′*, and by the vertical pipe V, which opens at the base of the chimney, it escapes and produces a sudden puff, which one always hears in a moving locomotive.

The rapidity with which these noises, produced by the escape of the steam, succeed each other when the train is at full speed indicates the number of strokes of the piston in each cylinder. The number may be calculated according to the velocity of the train. In express trains this velocity reaches forty miles an hour, and if we suppose this distance run by a passenger-engine whose driving-wheel is 7 ft. 9 in. diameter, or 24 feet circumference, the engine has made 8800 turns of the wheel, each of which corresponds to a double stroke of the pistons. This is $2\frac{1}{2}$ double, or 5 single strokes per second.

§ III.—The Principal Types of Locomotives.

If the locomotive has a special character which distinguishes it from other steam-engines, such as the fixed industrial engines, or the movable engines for navigation, it does not follow that it constitutes a single and uniform type. It is a *genus*, but this genus comprises numerous species and varieties.

These species, of which I can only describe the principal, have been successively formed for the many and increasing requirements of the various kinds of transport. Locomotives may be primarily divided into two very distinct types:—

The passenger-engines, solely destined to carry rapidly trains of no great weight. (Express service.)

The goods-engines, specially set apart for moving with moderate speed very heavy loads. (Slow service.)

Naturally a third type, intermediate between the two first, participating in their mean qualities, must have arisen. These are:

Mixed locomotives, employed to draw trains with passenger carriages and goods waggons together, or perhaps capable of being used either for fast or slow trains.

Besides these three principal types other forms of locomotives have been constructed for special purposes. We will pass in review some examples of each of them.

First the express passenger-engine *par excellence* (Fig. 317). This is Crampton's locomotive, characterized by the large diameter of its two driving-wheels, and the short stroke of the piston; two conditions which, joined to a high vaporising power, make it the race-horse of the iron way. For the thirty-five years that this excellent engine has been tried, it has not ceased to respond to all the demands of the service. It has great stability, arising from the lowness of the general centre of gravity, and the interval between its axle-trees. Of a mean weight of thirty tons, it will draw a train of twelve or sixteen carriages of 100 to 130 tons, with a velocity, including stoppages, of thirty-seven miles an hour.

A Crampton, without its tender, costs £2600.

The engines of Macconnell, Buddicomb, Sturrock, and Stephenson's three-cylinder, are also good express engines. The third

cylinder in Stephenson's engine is to prevent an oscillating motion which the locomotive receives under the action of the two lateral pistons, and which is shared in by all the carriages of the train. One is reminded that it is partly for motives of equilibrium that M. Dupuy de Lôme has employed three cylinders in marine engines.

We may take in the same way the Engerth type as the most marked of the locomotive engines for slow service, used to drag heavy loads. On looking only at its general physiognomy, and comparing it with a Crampton engine, one sees in an instant that we are dealing with a powerful engine, and if one may be compared to a

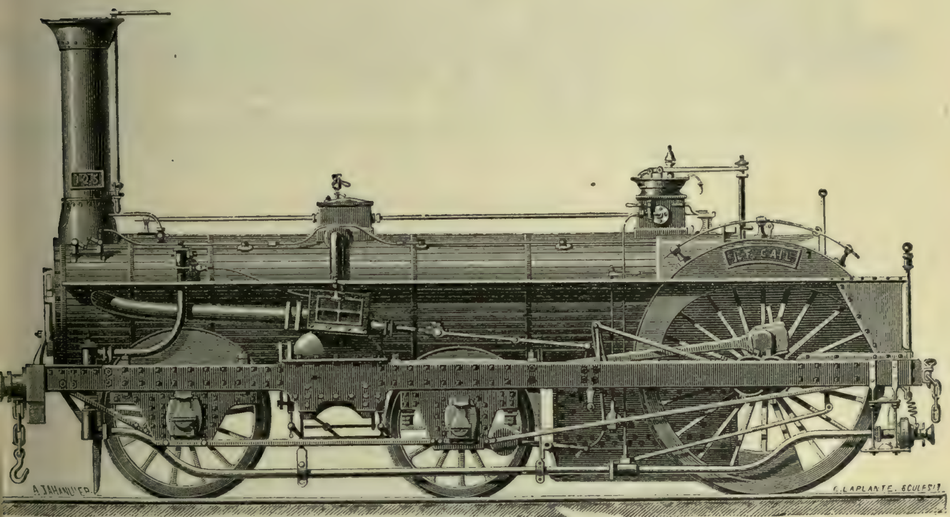


FIG. 317.– Express engine: Crampton's type.

race-horse, the other may no less fairly be compared to a cart- or draught-horse.

The mean velocity of an Engerth (for there are several varieties) is 15 miles per hour; but they can drag a load of 450 tons. Their weight is as much as 63 tons, which is borne partly, along with the tender, on the wheels of the latter, but which is principally supported by four pairs of wheels of equal diameter, coupled by connecting-rods. Contrary to Crampton's type, the goods engines of this type have several pairs of driving-wheels—of small diameter—and a long stroke for the pistons of their cylinders. Great length is given to the

boiler the cylindrical body and the tubes, and great dimensions to the fire.

In this, in the large heating surface, and the vaporizing power of the boiler, lie the secret of the enormous force of traction with which this remarkable type is endowed.

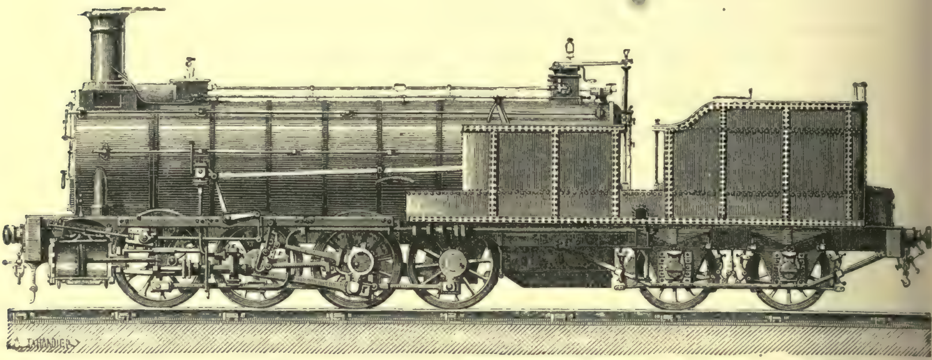


FIG. 318.—Goods engine for slow trains: Engerth's type.

The first Engerths[1] were provided with a set of cog-wheels, with the object of enabling them to ascend the inclines of the Sœmmering. The types of mixed engines, or locomotives of moderate speed, partake of the characters of the two first types. Two pairs of coupled

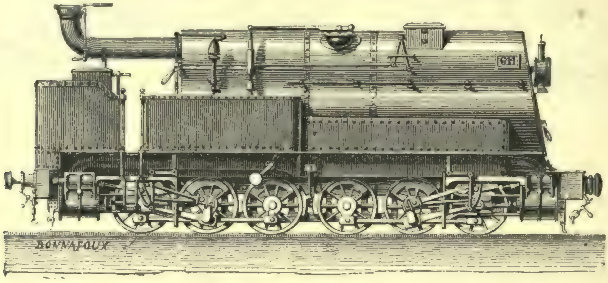


FIG. 319.—Goods engine on the Northern Railway of France, with twelve coupled wheels and two cylinders.

wheels of a diameter varying between 1·50 and 1·70 metres, a moderate length of the stroke of the piston, a weight of about 25 to 30 tons, the regulation velocity 29 miles per hour, a force of traction of 180

[1] So called from the name of the inventor, an Austrian engineer, who designed them at first for use on lines with heavy inclines.

to 200 tons; all these elements, it may be seen, are comprised in the corresponding elements of the extreme types.

Then comes that class of locomotives, sometimes economical and of small relative power, sometimes costly and complicated, but possessing a force of traction which makes them capable of drawing the heaviest loads in damp and rainy seasons, and of ascending the heavy inclines now adopted on a large number of new lines. These last machines, of which Fig. 319 represents a model, are called *mountain locomotives*, or *engines for gradients*. It would be necessary for completeness to multiply discussions and figures, to mention the pilot-engines, which give warning or help those drawing too heavy a load, the extra engines sent out in cases of accident, besides the types on foreign lines, the locomotives of German and American railways, heated with wood, whose pointed buffers, rail guards, and chimneys widened at the top, give them so original an appearance. But details so complete and circumstantial would exceed the scope of this work.

§ IV.—Compressed-Air Locomotives.

Before we quit the subject of locomotives and railways, there is another kind of engine to be referred to which we introduce in this place in order that the action of steam may be compared with that of another gas under pressure—namely, compressed air.

The boring of a tunnel of any importance presents difficulties of various kinds, among which may be mentioned the clearing away of the rubbish arising from the excavation of the gallery, whenever that reaches any considerable length.

Thus in the St. Gothard Tunnel the work was begun from two points, Airolo and Gœschenen, the two extremities of the future tunnel. The advance of the gallery, which is pushed on with activity, produces about 400 cubic metres of rubbish a day at each of the two faces of attack. To carry away this mass of rubbish, which is thrown regularly into trucks running on rails, it is impossible to employ steam locomotives as the *cul de sac* nature of the galleries prevents effectual ventilation. The high price of horses and the large number required prevent their use. The idea suggested itself of making use of compressed air locomotives. We have already shown how

compressed air is used to work the perforating machines used in boring the tunnel; by the employment of compressed-air locomotives

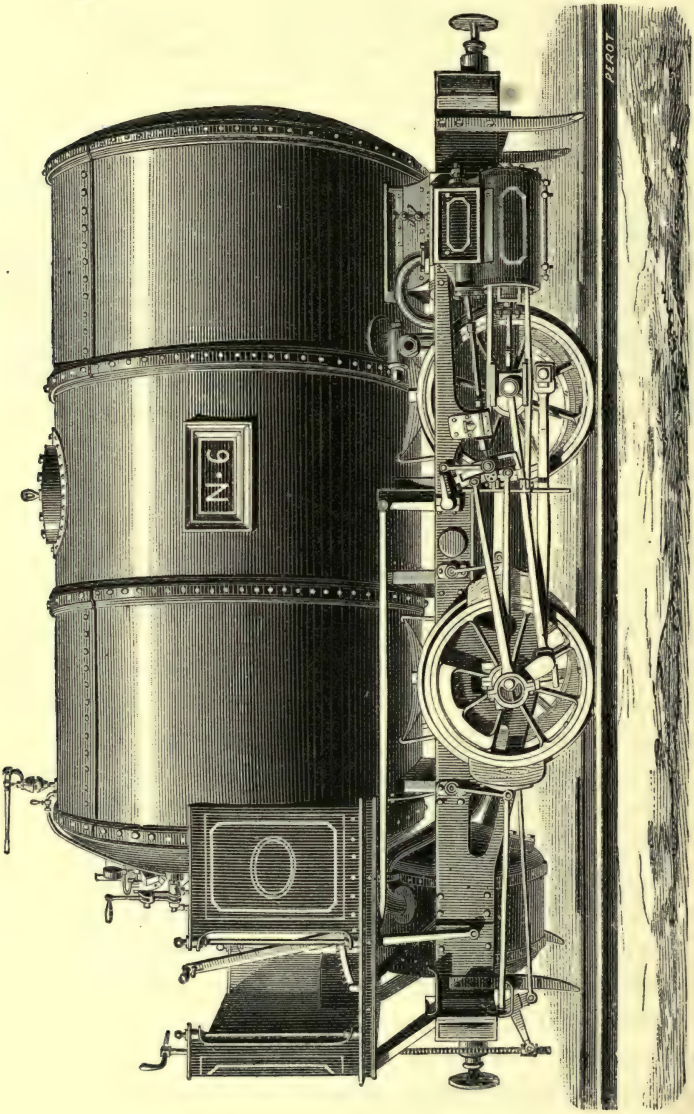


Fig. 320.—Compressed-air locomotive used at the St. Gothard Tunnel Works.

ventilation of the galleries would be produced, as these machines would allow only pure air to escape.

A first attempt was made in which two ordinary locomotives were

employed, one at each side of the tunnel; the boilers, in which, of course, there was no water, were filled with condensed air under a pressure of four atmospheres. This air played the part usually done by steam, passed into slide valves, entered the cylinders alternately on each face of the pistons, which it set in motion, and then escaped into the atmosphere.

It is easily seen that if compressed air were to be employed, it would be indispensable to have a very considerable quantity of it; the boiler of a locomotive, sufficient when it is worked by means of steam constantly produced under the action of heat, was too small to contain a quantity of air sufficient for use without being filled. This led to adding to each locomotive a special reservoir for compressed air; each locomotive was accompanied, as a kind of tender, by a long sheet-iron cylinder, 8 metres long and $1\frac{1}{2}$ metres diameter, supported towards its extremities by two trucks, which, on starting, were filled with condensed air, and which communicated by a tube with the

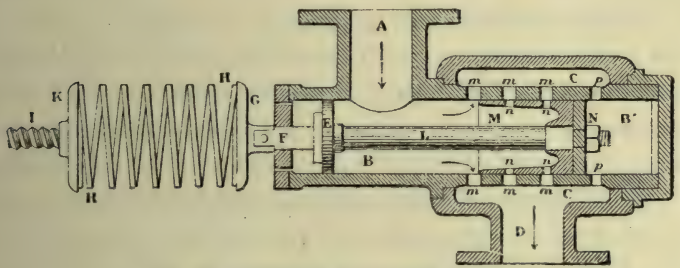


FIG. 321.—Mechanism for regulating the pressure.

distributing apparatus of the cylinders. The locomotive then worked as before, except that compressed air came from the reservoirs instead of from the boiler. The two locomotives, the *Reuss* and the *Tessin*, worked economically for about two years, in spite of the awkwardness of the long cylinders that accompanied them. At departure the pressure in the reservoir was about 7 kilogrammes per square centimetre; the locomotive having drawn a train of twelve loaded waggons along a course of about 600 metres, the pressure was found to fall to $4\frac{1}{2}$ kilogrammes; the train then returned empty to the point of departure, and the final pressure was found to be $2\frac{1}{2}$ kilogrammes.

In spite of the relatively advantageous results which were obtained,

the employment of compressed air in a steam locomotive presented a certain number of drawbacks. It is expedient that the air should issue from the cylinder under the least possible pressure, in order that refrigeration may be reduced to a minimum; for it is known that the expansion of gas is accompanied by a loss of heat which increases with the pressure.

On the other hand it is necessary that the air should arrive in the distributing apparatus with the least possible pressure, for it is in this apparatus, in the slide-valve, that the greatest losses take place, and these losses increase in proportion to the pressure.

M. Ribourt, the engineer of the tunnel, has devised an arrangement which allows the compressed gas to flow at a fixed pressure whatever may be the pressure in the reservoir. The gas in escaping from the reservoir enters a cylinder B (Fig. 321), over a certain extent of the walls of which are openings *m m*, that communicate with another cylinder C, which surrounds it to the same extent, and which is connected with the slide-valve by which the air is distributed, or, more generally, with the space in which this air is to be utilised. On one side moves a piston, E, which shuts the cylinder and hinders the escape of the air. This piston carries externally a shaft, F, which supports externally a spiral spring, H, the force of which is regulated by means of a screw. Internally it is connected by another shaft, L, with a second piston, N, which bears a cylinder, M, movable in the interior of the principal pump, and forming thus a sort of internal sheath. This sheath presents openings, *n n*, which may coincide exactly with those already referred to, and in that case the gas passes without difficulty from the reservoir at the point where it is to be employed. But if the sheath is displaced, the openings no longer correspond, there is resistance to the passage, and consequently diminution of the quantity of gas which flows out, and hence lowering of pressure in the exterior cylinder. By making the position of the sheath to vary continuously we may make the pressure of exit constant, notwithstanding the continuous variation at entry. But the apparatus is automatic. In fact the part of the cylinder B comprised between the bottom and the piston N communicates by openings, *p* (which are never covered with the escape-tube of the gas), in such a manner that upon its posterior face the piston N receives the pressure of the gas at the moment when it flows, a pressure which it is sought to render

constant. The piston E receives on its anterior face the action of the spring, which can be regulated at pleasure. As to the other faces of the two pistons, they are subjected to equal actions proceeding from the pressure of the gas at its entry, actions which thus counteract each other; so that the forces which determine the position of the movable system are on the one hand the tension of the spring, a constant and determined force, and on the other hand, the pressure of the flowing gas; and thus equilibrium cannot occur unless the two forces are equal. If the gas should flow in too great quantity, the pressure increases on the posterior face of the piston N, the spring is overcome, and the movable system advances a little towards the left; but then the orifices are partly covered and the flow diminishes. If the pressure then becomes too weak at the exit, the spring in its turn prevails, pushes the sheath towards the right, uncovers the orifices, and consequently a greater quantity of air may enter.[1]

§ V.—STEAM-CARRIAGES, OR ROAD-LOCOMOTIVES.

The first steam-carriages were designed for and used upon ordinary roads before the invention of railways. We have seen that they could not succeed.

Now the reasons of this want of success were manifold; some arose from the relative imperfection of the steam-engines employed for the purpose, as also the driving machinery, others arose from the very nature of the road on which these carriages were to move. The power of a locomotive has some relation to its weight, although it would be erroneous to believe in this case in the necessity of increasing the weight in order to increase the adhesion. The wheels, and especially the driving wheels, support this always heavy weight, and discharge themselves of it on the road itself at the points where they are in contact with it. Now, however well laid and paved the road may be, the ground yields to the pressure, ruts are formed, and at the end of a short time the engines come to a stand on the road.

In London in 1862 Bray's locomotives were employed to draw heavy loads on the ordinary macadamized or paved roads, in trenches

[1] For this description the editor is indebted to an account given in *Nature*, April 2, 1876.

or trams, loaded with burdens too heavy to be moved by horses. In 1864 experiments were made at Nantes with a road-engine, constructed by one of the most experienced of French mechanicians, M. Lotz. In August of the year following these experiments were repeated at Paris, and gave interesting results.

With a load of five to six tons the velocity of Lotz' locomotive reaches ten miles an hour on a road in good condition; it will draw a load of 12 to 15 tons at the rate of $3\frac{3}{4}$ miles, ascending slopes varying from 7 to 13 inches in a hundred.

One of the disadvantages of this method of transport is the great variation in the amount of work to be done by forces which remain sensibly constant. Larmanjat's locomotive takes this difficulty into account. For the large driving-wheels, going at the rate of ten miles an hour, can be readily substituted two of smaller diameter, working with the former and placed inside them. This substitution diminishes the velocity of the engine, and if this be reduced by one half, the force of traction will be doubled, and the locomotive can then overcome obstacles which the slope or bad state of the roads may oppose to its passage. An engine of this sort was shown at the Paris Exhibition in 1867. It was of 3 horse-power. "It started from the Auxerre terminus, drawing a heavy truck with low wheels, carrying a load of about three tons, and with this load it was able, by the employment of its small wheels, to ascend a long incline of 8 in a hundred with a mean velocity of five miles an hour." Other experiments, made continuously in the suburbs of Paris, have been very favourable, it seems, to this system. The view we give of M. Larmanjat's road-engine (Fig. 322) is taken from nature, on one of the numerous trials recently made in Paris in the Trocadero.

We ought also to mention M. Albaret's, of Leancourt (Aisne), road-engine, which has been tried for two years in the Départements du Nord and the Jura, drawing loads of 12 tons on roads with inclines of 5 or 6 in the hundred, with a maximum velocity of $3\frac{3}{4}$ miles an hour, and that of M. Garret, which has drawn a diligence with 15 passengers from Auxerre to Avallon and back at a mean velocity of 7 miles an hour.

The English and Americans have not been behindhand in this kind of research. They have made many attempts to solve practically the question of steam-locomotion on ordinary roads. The difficulty

has been of course to avoid the ruts occasioned by the weight of the engines. With this object Boydell employed an endless rail, which placed itself in front of the wheel, and rested on the ground by means of broad shoes. The complication of the machinery and the small velocity obtained led to the abandonment of this system. Bray adopted iron wheels of large dimensions, provided along the circumference with movable grippers, but the result was that the roads were quickly spoiled. To solve the same problem Thomson of Edinburgh covered the fellies of the driving-wheels of his engine with vulcanized India-rubber bands 5 inches thick and 1 foot broad.

FIG. 322. – Larmanjat's road-engine.

These bands [1] perfectly support the weight of the engine, and roll on ordinary roads without breaking the stones that lie on the surface. Owing to the elasticity of the india-rubber, the contact between the felly and the ground is not confined to a line, but takes place on a surface over which the pressure is distributed. The wheels therefore do not bury themselves in the ground, and even if it is made to pass over newly-made roads, it will traverse the freshly broken stones without the band being cut or spoiled. The force necessary to drive a locomotive of this sort is therefore much less than that necessary

[1] See an article by M. Sauvée in the *Industrial Annals*, an excellent review, from which we borrow the drawing of Thomson's locomotive.

for an engine with smooth iron bands, for in the latter case the wheel crushes the ballast and causes a considerable loss of force.

A locomotive of this kind might be driven in a prairie without leaving any great marks of its passage. On a horizontal road, it can draw 30 tons with a velocity bearing from $2\frac{1}{2}$ to 6 miles an hour. Its effective force is from 16 to 18 horse power. Many are employed in different parts of England to carry coal from the pit to neighbouring factories, and in Edinburgh. Thomson has applied his locomotive to the traction of omnibuses. Lastly, attempts have been made in India

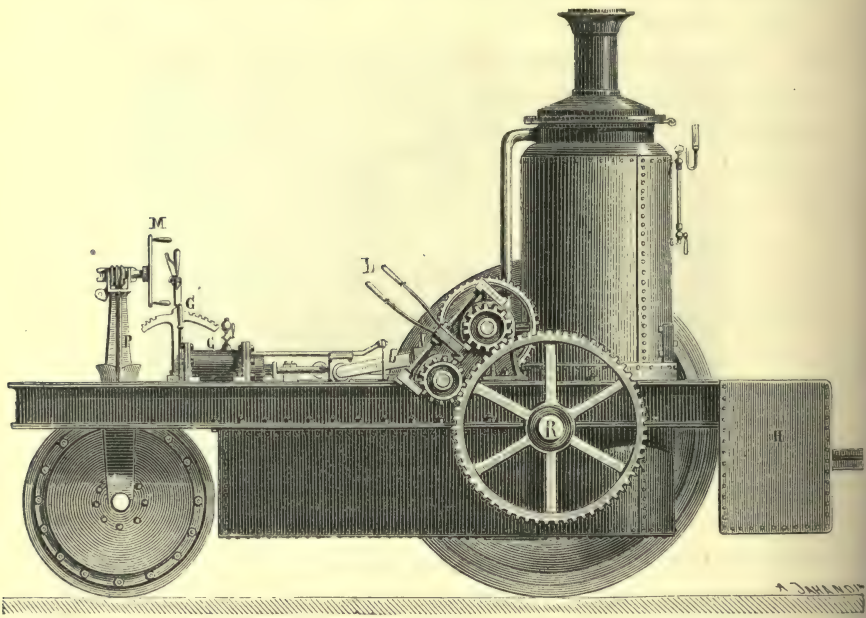


FIG. 323.—Thomson's road-engine.

with these engines, in the postal service, for carrying its bags, in the province of Punjaub between the towns of Loodlana, Ferozepore, and Lahore.

The design we give here of Thomson's road-engine will suffice to render the general arrangement of the parts comprehensible. We see that the steam-engine has a horizontal cylinder, C, communicating the motion by a connecting-rod to a doubly-bent driving-shaft provided with a pinion, working in a cog-wheel, fixed on the driving-wheel. On account of this arrangement the velocity given to the axle R of the

driving-wheels of the carriage, depends, with the same velocity of the piston, on the number of teeth in the wheel and the pinion. But the driving-shaft has another pinion, which works in a second wheel, itself fixed on another driving-shaft parallel to the first, and this last, by a third pinion, communicates its motion to the first cog-wheel. It is of course understood that these two systems work independently. The conductor passes at pleasure from one to the other, by the aid of adapting levers within reach. He can thus vary the velocity of the driving-wheels, for the same work of the steam, in a ratio which varies from the simple to the double (more exactly from sixteen to thirty nine).[1]

Of late years in England efforts have tended in the direction of effecting rapid transit on tramways by means of compressed air, and of giving up high speed on ordinary roads altogether. The use of the traction-engine for heavy loads is, however, increasing; that chiefly used, designed by Aveling and Porter, is shown in the annexed woodcut.

It would appear that the action of the traction-engine on the roads on which it has travelled has given rise to a new employment of steam, for in the *steam-roller* we have a locomotive the object of which is to make smooth roads rather than use them. In principle it will be seen the steam-roller is a locomotive with a great development of weight and width of wheel.

The engine is carried upon four rollers of equal widths, the two hind ones acting as drivers, and the two in front as steering-rollers. These latter cover the space between the two driving-rollers, and are made slightly conical in order that on the ground line they may run close together while leaving room above their axle for the vertical

[1] The mechanical problem of steam locomotion on ordinary roads may perhaps, as we have seen, be considered solved. Can we say from this that the employment of road locomotion will become general? It is difficult to answer this question, for besides the technical aspect of it, there is the industrial and commercial. This means of transport would have to be really economical; and this evidently depends on a variety of circumstances in no sense connected with mechanics. In great cities, such as London and Paris, where the requirements of locomotion are so continuous and pressing, road-engines may perhaps be usefully employed, if means could be devised to render it prudent, and to guard against the dangers that would arise every instant in meeting carriages and foot passengers. It is probable that this mode of locomotion will be tried, and perhaps definitely adopted, on some of the tramways.

shaft which connects them to the engine, and which serves to support the forward part of the boiler; at the same time play is given to the

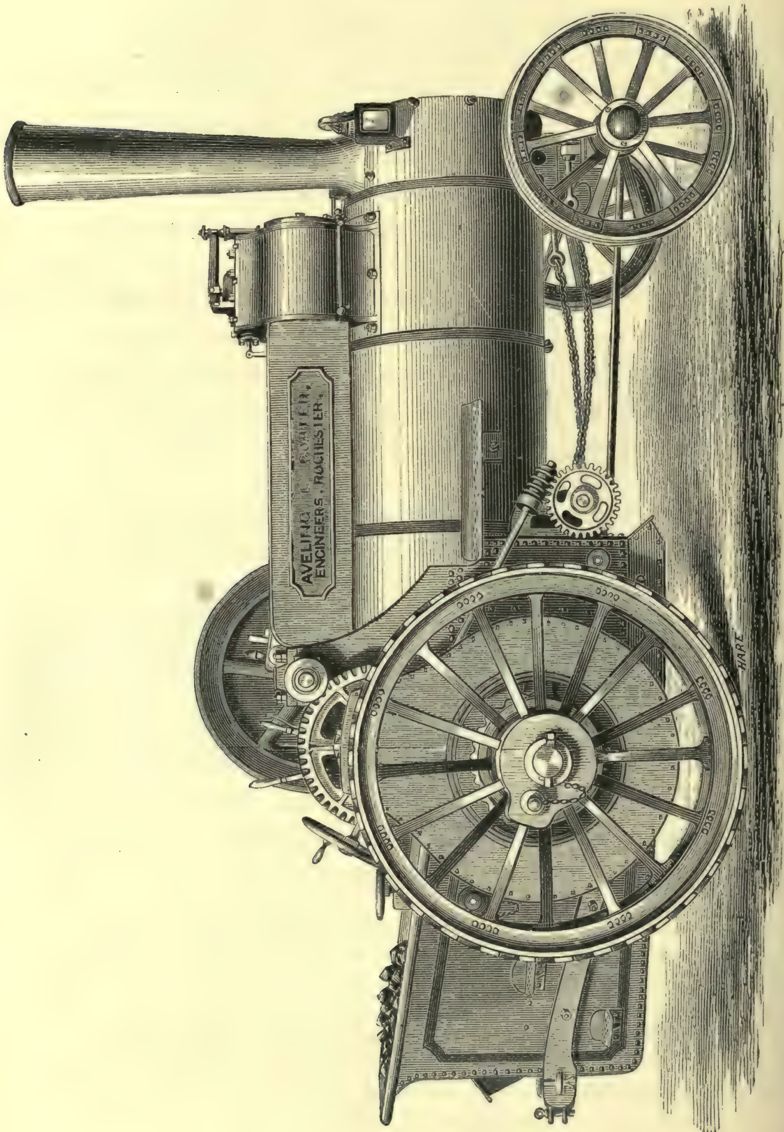


FIG. 324.—Aveling and Porter's traction engine.

vertical shaft for the rollers to accommodate themselves to the curved surface of the road. The machine can be turned round in little more

than its own length, thus enabling it to roll steep hills without injury to the fire-box, while retaining the manifold practical advantages of

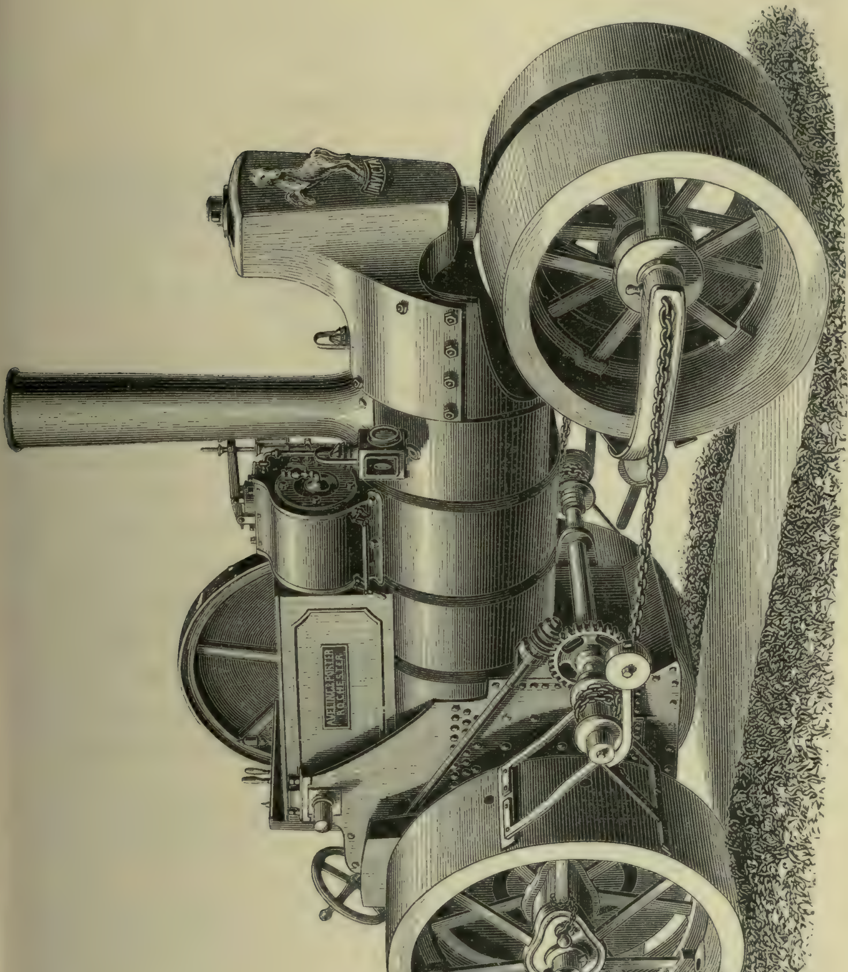


FIG. 325.—Steam-roller.

the horizontal over the vertical boiler for locomotive purposes; amongst which may be enumerated absence of priming, economy in

fuel, wear and tear, and much lower centre of gravity. These rollers are adapted for driving stonebreakers or other fixed machinery most economically, when not required for rolling; and for use as traction engines.

§ VI.—Portable Engines.

There remains to be examined a fourth type of steam-engines, recently introduced, the use of which is continually increasing, and which has no further resemblance to the locomotive than the name and outside appearance. Locomobile is the term given by the French to this class of engine.

In reality, a locomobile is a fixed engine, but it is movable from place to place. Relatively lighter and less cumbersome, it is placed like the locomotive on a framework and mounted on wheels. The boiler, the machinery, the fly-wheel, are all arranged in such a way as to require no more to set it working than supplying it with fuel and lighting it. When the engine has done its work at one place, it is taken to another, where its power is required, which is thus made use of in two places removed from each other. The wheels of the locomobile are not as in the locomotive the driving-wheels. They are absolutely independent of the machinery, and have but one object: that of allowing the engine to be drawn from place to place and across fields. By putting in two horses this is the easiest thing in the world.

This is a power now universally employed. In agriculture, and in industrial works, these locomobiles serve for many purposes, and replace with advantage the labour of horses or men.

In the construction of masonry of sufficient importance, locomobiles are employed to hoist the materials; they move the hoists, they turn the crushing-mills for making mortar, and are substituted for the workmen who raise the monkeys for pile-driving, or who work the cranes. Steam-cranes with movable engines may be frequently seen at commercial or military ports.

Locomobiles are employed for working the pumps fixed temporarily for draining earthworks. One of them might be seen at work in front of the Louvre during the siege of Paris; it

worked a pump, which poured the water of the Seine into the reservoirs established along the quays.

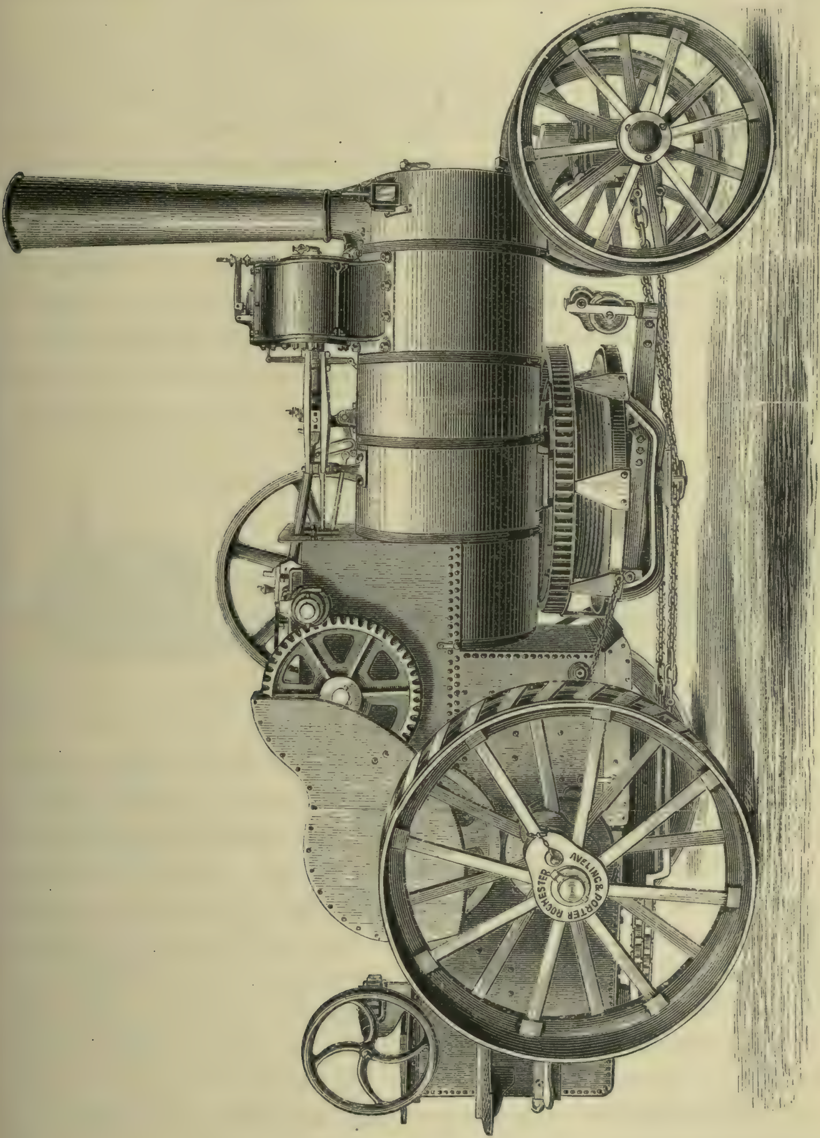


Fig. 326.—Aveling and Porter's steam ploughing engine.

In agriculture the introduction of steam-power has effected a revolution; threshing-machines, chaff-cutters, crushers, pressers, and

root-cutters are now frequently driven by steam. Wherever we have to do with large production it should be, and it is advantageous to substitute for the moving force of oxen or horses the moving force *par excellence*—steam.

But in no case has the introduction of steam-power been more revolutionary than in the case of ploughing. Of the many systems of ploughing by steam, two only have proved thoroughly successful; in both of these the traction power is transmitted to the plough through a steel wire rope winding upon a drum. In the one plan the two winding-drums are fixed in a windlass frame, and connected to a stationary steam-engine, which can be worked from one corner of a field; one end of each rope being made fast to the plough, the implement is drawn backwards and forwards by the drum pulling alternately, and the pulley sheaves and anchors at each end of the furrow move forward as the implement proceeds. In the other system each of

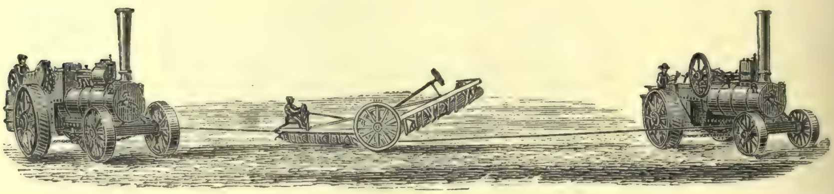


FIG. 327.—Direct system of steam ploughing.

the winding-drums is placed under the boiler of a self-moving steam-engine (see Fig. 326), and one engine at each end of the furrow alternately pulls the plough towards it, the other moving forward into position ready for the return of the plough. These two systems are known as the single engine or roundabout, and the double engine or direct method of steam cultivation. For large farms the double engine or direct system is the best. Land can be ploughed by it at one-half the cost of horse-power. Figs. 326 and 327 show the arrangements of the drum and the action of the two engines when used on the direct system.

Portable engines have received very varied forms, according to their destination and the ideas of their constructors.

The boiler is, as in the locomotive, a tubular boiler, composed of a grate A situated behind, and a cylindrical body BB, which incloses

the tubes. The power of these engines is small, they are made of one or two up to eight horse-power. There is not therefore any necessity for so large a heating surface as in the locomotive, so the tubes are larger and fewer in number.

The engine works at high pressure and without condensation, the steam being allowed to escape in the chimney so as to produce a draught. The draught ought never to be so great as to draw from the grate any lighted cinders, especially as these engines are employed in the neighbourhood of inflammable substances when engaged in agriculture, otherwise there would be a danger of fire.

Portable engines are not at all economical; they consume eleven to thirteen pounds of coal per hour for each horse-power. We have already said they are light, in fact the weight of an engine of four or five horse-power is not more than two tons.

§ VII.—Various Applications of Steam.

We have just seen what the steam-engine is; on what physical and mechanical principles its construction rests; and what are the various forms it has taken so as to be accommodated to the different services required of it in manufacturing industries, in transport by land and sea, in public works and in agriculture: it remains for us to say a word on the applications themselves to which steam is put and the immense part it plays in modern society.

The earliest steam-engines were employed as we have seen, to drain water from mines; they were the motors of powerful pumps, and they still serve for the same purpose. In large towns steam-engines are used to pump the water required for public and private use from the rivers and streams.

In England and Holland, steam-engines are employed to work the pumps that drain marshes and lakes, such as the lake of Haarlem, Zuid Plas; and the draining of the whole of the Zuyder Zee in the same manner is now spoken of.

The portable engine is everywhere employed now in public works; it raises the monkeys of the pile-drivers for building foundations on piles; the hoists in buildings, railway and seaport cranes. Steam moves the tow-boats or tugs of rivers and canals, ferry-boats and fire-

engines. Among the interesting applications of this mechanical power we must mention the thousand operations employed in making the engines themselves, especially the forging of large metal pieces. The instrument which serves this purpose is the steam-hammer on which we may give a few details.

The steam-hammer is, so to speak, a peculiar kind of steam-engine in which the force is directly employed to produce the motion of the instrument. Among the largest steam-hammers in existence those at Woolwich and in Krupp's famous works in Germany may be mentioned.

The steam-hammer which has contributed so much to develop the manufacture of iron, that chief material of modern machinery and industry, was invented by Mr. Nasmyth.[1] These gigantic hammers, which are employed in all the factories where iron or steel are forged in great masses, do not receive their motion from a steam-engine, but the steam directly raises or lowers them between two enormous uprights of cast-iron which serve as guides to their motion.

Fig. 328 shows how the hammer works. Imagine an iron monkey whose weight is fifteen tons moving itself between two uprights or slide-bars, suspended to the strong piston-rod of the cylinder into which the steam can penetrate at pleasure. This steam arrives by the pipe V, and thence by the port opened at the base of the pump beneath the piston, which is then driven upwards by the elastic force of the fluid. By means of a lever L, a rod T is acted on which lowers a lateral slide-valve, and the steam escapes into the air by a chimney UE. The steam acts here by a single expansion, but steam-hammers are constructed in which it serves both to raise the enormous weight, and to precipitate it downwards. M. Turgan, in his work, *Les Grands Usines,* refers to an enormous steam-hammer constructed at Kirkstall near Leeds, for the Victoria Railway Company in Australia. This hammer is either single-acting or double-acting, thus the steam acts in both directions, that is to say, it can alternately raise the hammer, and enter above it to quicken its descent, and to augment in consequence the action of its weight. This arrangement, which gives the power of multiplying the number of blows in a given time, is specially advantageous in forging pieces of

[1] In the French edition the invention is ascribed to M. Bourdon, of Creuzot.

very large size. The work may be done by its help, in one heating which effects a saving of time, fuel, and metal.

The effect of this powerful engine is equal to that produced by a weight of sixteen tons, striking forty strokes a minute. The alternate double and single action can be obtained instantaneously. By means of a slide-valve suitably placed, the fall and the force of the blow can be equally changed in an instant. We know that for hammers which act by their gravity, the mechanical work produced is represented by the weight of the mass multiplied by the height of the fall. The

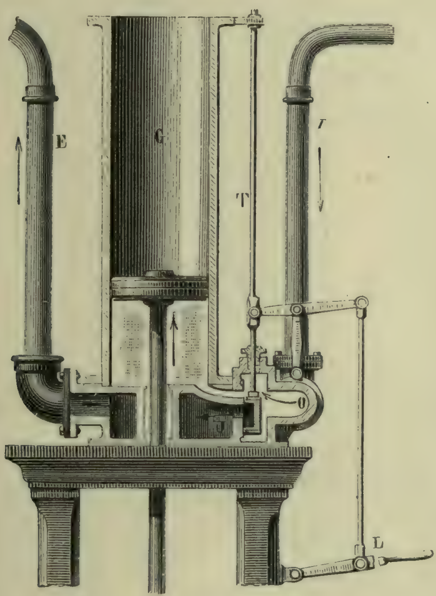


FIG. 328.—Steam block-rammer: section of the cylinder.

weight of the whole apparatus including the mass of the hammer, the anvil, the block, and the steam-engine, &c., is about 100 tons. The head of the Woolwich hammer weighs thirty tons, and when forced down by the whole power of the steam, it comes down upon the hot iron with an energy of more than 1000 foot-tons, the solid ground trembling for a great distance around in spite of piles, stone and concrete foundations more than fifty feet deep.

In great workshops, manufactories of engines, forges, and saw-

mills, fixed engines are always employed, and sometimes movable ones in addition: these give and distribute motion to all the works by means of cogs or straps. Planing, drilling, mortising, boring, screw-making, polishing metal surfaces are all done by the force of steam, and it is difficult to know which to admire most in these great opera-

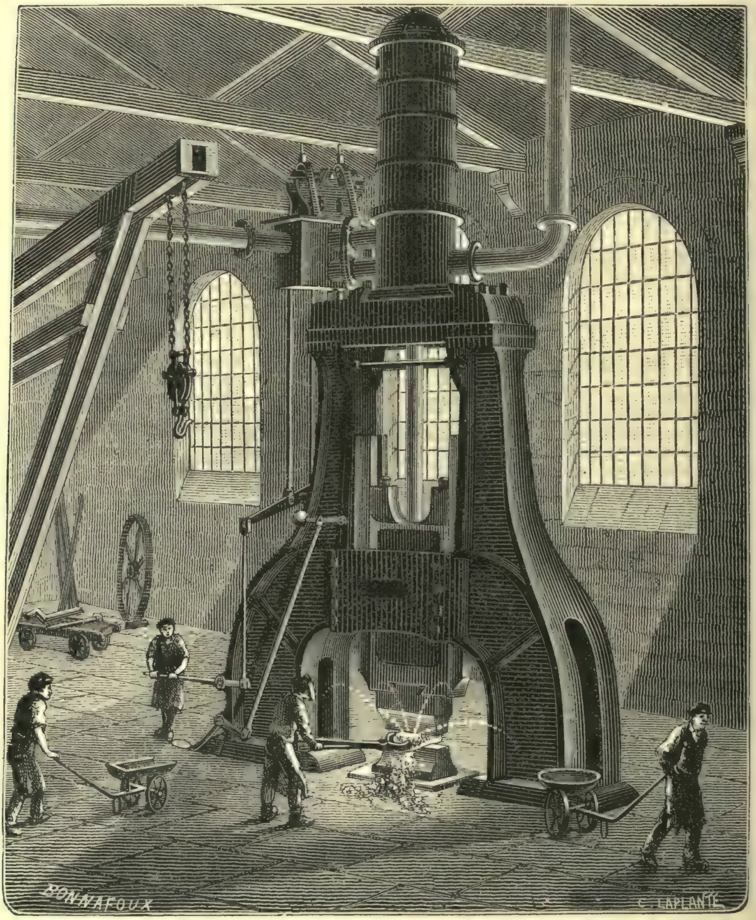


FIG. 329.—A steam block-hammer.

tions—the power of the engine, or the docility with which it adapts itself to any kind of work.

Is it not something marvellous to see the machine work steel and iron with as great ease as a workman handles wood, be he carpenter

or wheelwright; to see these shears cut off pieces of rough iron, and divide thick sheets of metal, like a tailor's scissors working on the softest material? Formerly iron was filed with difficulty, but now it is planed like wood, and is cut up and pierced like cardboard. Some Indret machines are so firmly fixed that they can take off a shaving of 40 mm. over a length of 11 metres; the holder that carries the planing-iron alone weighing fourteen tons. Among the most curious of the Indret machines, we ought to mention a Mazeline lathe for circularly planing bent shafts. Its planing iron is carried by a disc turning in a frame; the piece to be trimmed crosses this disc and advances against the holder, so as to present to the tool the successive points which have to be thinned off. We must likewise notice M. Calla's mandrel lathe, the bed of which is five metres in diameter, and the benches for boring and drilling cast and wrought-iron and brass in every known way.[1]

If we wished to enumerate and describe, even summarily, all the uses of the steam-engine in modern industry, we should not require a chapter only, but a book, and a large book too. It is used in blast furnaces, where horizontal engines work as bellows for keeping up the fires; at the diamond cutter's, where steam gives to the grinders the prodigious velocity of 2500 turns a minute; in brass foundries, where it works the pumps that transfer the molten metal; in paper manufactories, where it works the machines for washing and whitening the paper; in the manufacture of tiles, of bedding, and pianos; at the wood-cutter's, and workers of arabesques of all shapes; at the jeweller's, at the mint where the Uhlborn presses, improved by Thonnelier and moved by steam, strike off 2400 coins in an hour; in tobacco and chocolate factories, and indeed in a hundred other industrial operations where a powerful, regular, rapid, and continuous motive power is used. But it is in the large manufactories that steam plays so immense a part—in cloth and cotton factories supplying clothes for the whole human race, and in typographic and lithographic printing which gives us intellectual food in the most assimilable form,—the book and the drawing.

A few words as to the application of steam to printing. It was in November, 1814, that by means of a press invented by F. König, the first sheets printed by steam were struck off. The *Times* newspaper

[1] Turgan, *Les Grandes Usines de France.*

had the honour and profit of this first attempt which produced 1,000 copies an hour.

The most perfect printing machine which exists now is called

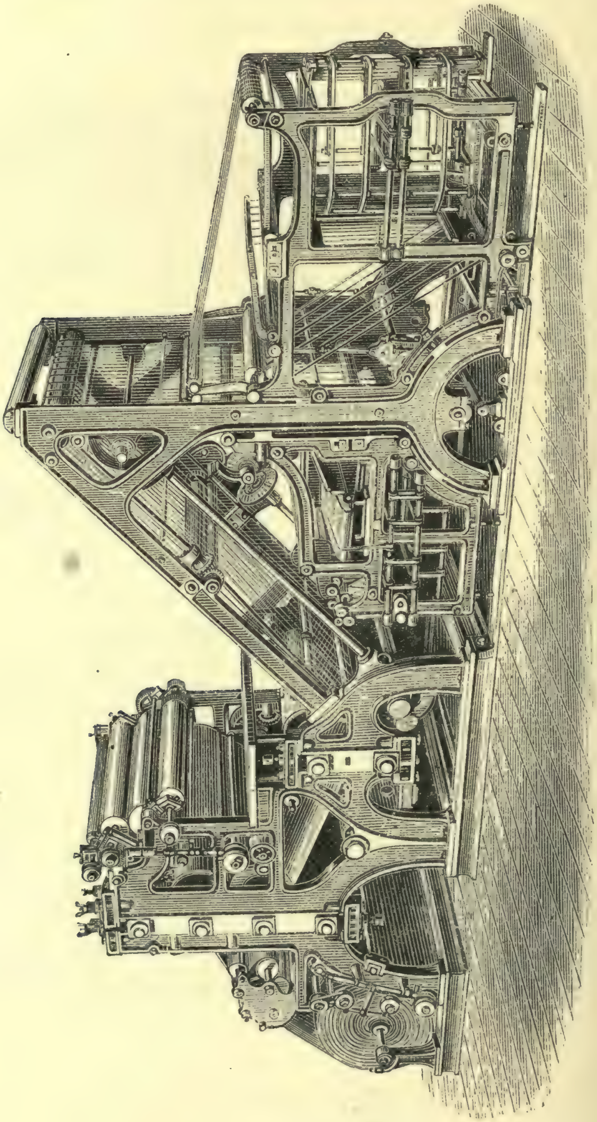


FIG. 330.—The latest form of the Walter press.

the Walter Press, which has been invented and elaborated in the office of the *Times*. The fastest printing machine hitherto in use

—the "Hoe ten-feeder"—requires some eighteen people to feed it with paper and attend to it while at work, and even then can only produce some 7,000 or 8,000 copies an hour of perfect newspapers, because it only prints one side at a time. But the Walter Press, attended by a man and two boys, none of whom are severely worked, runs off with ease complete newspapers at the rate of 12,500 an hour.[1]

The foundation of printing by steam lies in the power of multiplying metal counterparts of the type "formes" by stereotyping. Type itself could never be made to fit on to a Walter machine with the requisite facility; but if a solid cast of the type can be obtained of the proper shape and cleanness, that difficulty is at an end—the first important step is gained. It is a twofold difficulty. In the first place, the page of type from which the impression is taken on a Walter Press must be bent in a semi-circular form and made to fit on to a large roller. In the second place, without a means of multiplying the metal type formes from which the paper is printed, even a speed of 12,000 or 13,000 copies an hour would in these days stand a newspaper in small stead. It would take the best part of a night to throw off an impression, and the *Times* does not go to press with its inner sheet till some time past four o'clock in the morning. Stereotyping is, therefore, absolutely essential, and the process as practised for the Walter Press is beautifully simple. The subject matter is, of course, first set up by hand, and columns are made into pages, and placed in a strong metal frame upon a metal table perfectly flat, and tightened up so as to form an immovable mass. When that is satisfactorily accomplished it is conveyed to the stereotyping room, where some layers of damp paper are laid upon it, and it is then driven twice through a machine having powerful rollers, which squeeze the paper down on the face of the type. It is next placed —with its damp paper still on it—below a heavy screw-press, the sole or lower plate of which is a steam-heated metal chamber. This dries the paper rapidly, and at the same time the pressure put upon it prevents any inequality. In a short time the frame or page of type is drawn out from below this press and the dried paper peeled off its surface, when it forms a perfect matrix or counterpart of the

[1] For this account of the Walter Press the Editor is indebted to an article in *Macmillan's Magazine.*

type sufficiently deep to enable a casting to be taken from it which shall yield a page of clear-cut lettering, ready for printing from. Before the casting is taken, however, this paper matrix is made absolutely dry by being placed on another hot plate. That only occupies a very brief space of time, and when it is satisfactorily finished the paper is trimmed carefully, and then placed face upward inside a semi-circular mould, when its edges are fastened down by bands of iron of the thickness that the cast is meant to be. On these bands a counterpart of that mould is then let down from a small crane, and fastened so that a semi-circular chamber is formed the size of the page of the newspaper, and about three-eighths of an inch deep all round. Into this a pot of molten stereotyping metal is poured, the mould having first been turned on end so as to compel the metal to fill the cavity completely, and, after resting for a moment or two till the metal has set, the inner part of the mould is removed by the crane, the paper matrix is peeled off, scarcely browned, and capable of being used again and again, and the solid cast is swung round and deposited, still adhering to the mould, in another cavity exactly the shape of that from which it was taken. Here its edges are trimmed, and the lump of metal which formed the excess at the top of the casting sawn off by a small revolving saw driven by steam. That done, the cast may be said to be complete. The page of lettering now presents the appearance of a strong, solid half-cylinder of white metal, ribbed on the inside so as to facilitate the paring off of possible inequalities, and covered on its outer face with crisp, clean, shining letters, ready at once for the press; and the whole of the work of stereotyping is done. Now the work of steam begins.

The first thing to understand regarding newspaper steam printing is, that it does not print sheet by sheet, as all machines hitherto have done, but that it prints from a continuous roll of paper, from which it cuts off the newspapers sheet by sheet as it passes them out at the other end, perfectly printed. This web of paper is, therefore, the first thing that catches the eye on entering the machine-room, and is itself the result of no little effort to adapt means to ends. A web making some 5,500 sheets of the *Times*, all wound on one reel, is placed behind each machine, and when printing commences, the paper runs continuously through the press,

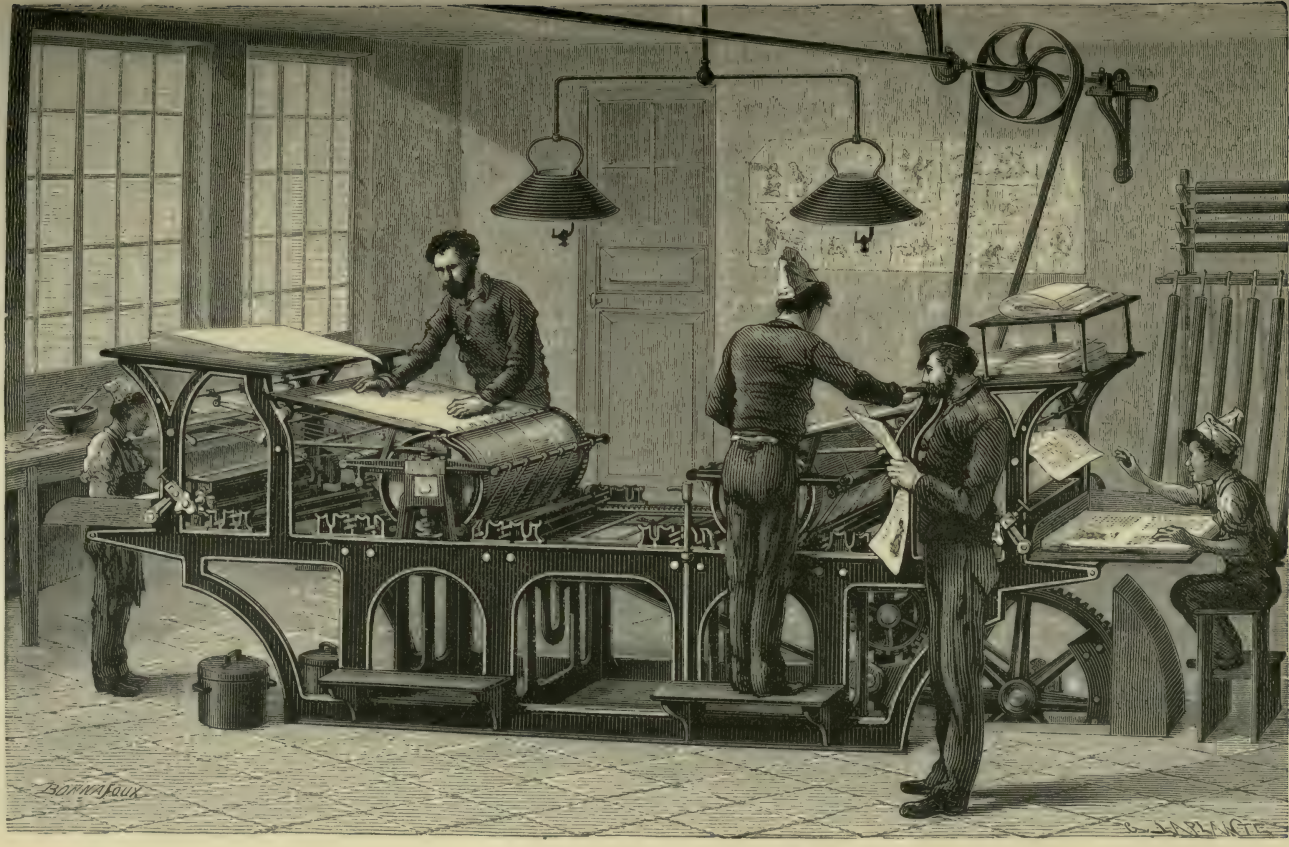


PLATE XVII.—STEAM APPLIED TO PRINTING.
Steam printing-press machinery for book printing.

passing first over some wet rollers, which damp it, water continually oozing out through folds of cloth from a supply contained inside the rollers, and which rapidity of revolution forces outward. From these rollers it goes upward to where the stereotype plates forming the four pages of one side of a sheet of the paper are fastened on a cylinder just large enough to take a sheet to go round it. Against that cylinder there is another, identical in size, possessing a soft surface, which presses lightly against the edge of the type, and between these the sheet passes, taking up an impression as it goes. It is then carried downward round another large cylinder, covered with cloth, the "set off" on which is taken off by another cylinder in contact with it, and that again by a rubber, in a fashion that is both simple and effective. The web of paper, still running on, passes, between the second type-covered roller and its counterpart taking the impression on its other side of the remaining four pages; and, that done, it runs out between two more rollers of the same circumference. The machinery is so adjusted that the knife catches the paper exactly between each sheet, and, the paper being held hard on each side by the spring bar, cuts it in two, all but a couple of tags near each end, which are left for the purpose of pulling the sheet on between two sets of running tapes, until it is caught by a pair of small rollers, which are driven at a greater speed than the rest of the machine. These immediately tear the sheets apart where they have been all but cut, and the tapes hurry on what is now a completely printed newspaper up an inclined plane, at the top of which they carry it down an oscillating frame which moves pendulum-wise so exactly that it delivers a paper precisely at each end of its short swing on to the face of another set of running tapes, which carry it downward on their outward face by the mere force of contact as they run. Between these tapes a frame, like a huge comb, swings backward and forward, catching up one delivered paper at every motion and flinging it down on a board, behind which a boy sits to watch and adjust the sheets as they fall. The current of air raised by the motion of this frame suffices to hold each succeeding sheet against the tapes along which it moves. Thus two boys and the man who attends the machine are all the manual labour required, and the manner of delivering the papers alternately on to two inclined boards ready to receive them gives the boys plenty of time to see that they fall properly,

to adjust those that may be slightly crumpled, and to inspect the work.

We have ventured to reprint these details regarding one modern special use of steam, as it is the one by which civilization and a knowledge of science is being most rapidly advanced.

For some years past steam and machine presses have been employed in lithography, though previously they had been only used in typography. The results obtained are remarkable; and the rapidity of printing has introduced an important economy into an industry which the rivalry of typographical productions was seriously menacing.

§ VIII.—STATISTICS OF STEAM-ENGINES.

We will conclude this rapid review of the innumerable applications of steam by giving some statistical facts of a general nature calculated to prove the truth of the following assertion, that steam is the origin of the most fertile revolution that has hitherto transformed the producing processes of mankind; and to justify the name of *the age of steam* sometimes given to our times.

In England, according to Fairbairn, the total amount of horse-power employed reaches the enormous number of 3,650,000—a force equivalent to the labour of 76,000,000 workmen, that is, more than twenty times as great as the total number of hands employed in British industries. In 1874 the export of articles manufactured by steam brought 138 millions.

In 1865, there were in France 19,724 steam-engines having together 242,209 horse-power. In this number locomotives are not included, and they number more than 4,000. This is for France an increase of productive power equivalent to a working population of more than 5,000,000 men; a result certainly exceeded at the present time. In Paris alone at the same time there were 1,189 engines moved by steam, with a total of 9,782 horse-power; or if we include the suburbs (in the department of the Seine only), there were 2,480 engines with a total horse-power of 19,150. To reckon the locomotion on railways of passengers and merchandize would greatly increase the services, which, according to the above figures, steam renders to that country.

Figures are not forthcoming about the manufacturing industries of other countries of Europe or of America. But we may gain an idea of what they probably are by considering the immense development that has taken place in the network of railways over the entire globe, a network traversed night and day by steam, which is also continually increasing its hold on the navigation of seas and rivers and lakes.

Up to 1875–76 the length of all the railways of the world reached a total of 176,141 miles, or nearly seven times the entire circumference of our planet. They are distributed as follows:—

Europe	83,864
America	82,335
Asia	6,822
Africa	1,675
Australasia	1,463

Locomotives now even pour forth their clouds of steam in India, Australia, and Japan, and steamboats are ploughing every sea. The navy has, in fact, followed the example of the manufacturing industries and the land transport, and though on a smaller scale, yet in an always increasing proportion.

In Europe, of 100,000 ships, forming nearly the total number of the mercantile marine, 4,500 ships employ steam, the tonnage of the latter greatly exceeding the tonnage of the sailing vessels. The number of sailing vessels employed in the home trade in Great Britain and Ireland was reduced from 11,000 in 1861 to 10,800 in 1874, while in the same time the number of steam vessels similarly employed had increased from 448 to 1,128, and in the foreign trade from 477 to 1,597. The number of new ships built in the same year was—

	Sailing Ships.	Steam Ships.
1861	774	201
1874	499	482

All these facts indicate the rapid conversion of a sailing into a steam marine. The total tonnage of all vessels rose from 26 million tons in 1861 to 45 million tons in 1874.

The total number of sea-going steamers in the British navy was, in 1874, 109, of which 16 were ironclad line-of-battle ships or frigates.

In France while the mean tonnage of sailing vessels is 60 tons, it reaches 280 as an average for steamships. The total number of French vessels in 1873 reached 14,750; of these, 462 were steam vessels, of 141,000 tons in all, and 57,000 horse-power.

§ IX.—Explosion of Steam-boilers.

We have recounted the benefits for which civilization is indebted to the invention of the steam-engine, and the progressively increasing introduction of this powerful force into every kind of industry. We must now make mention of the mischiefs it has occasioned, the lamentable accounts of which we read from time to time in the papers. Every medal has its reverse. All explosions of steam-engines have in reality but one simple cause: for one reason or another the pressure of the steam produced in the boiler exceeds the limit of resistance of the sides, the metal is torn asunder, bursting under the irresistible force of the gas, and casting about its fragments, covers the neighbourhood with the ruins and its victims. To the mechanical effects of this terrible outburst are added those which a volume of steam at a high temperature cannot fail to produce. The stoker, the assistants, the drivers, everyone in fact whom the metallic *débris* or the scalding steam encounters are horribly wounded, burnt, or scalded.

What are the causes of the explosion? Only that we have just mentioned.

An abnormal increase of pressure may arise from the following causes:

1. Depression of the water level, the consequence of which is an elevation of temperature at the metallic surfaces subjected to the action of the incandescent gases of the fire, without their being cooled by the water of the boiler within. These surfaces become red hot, their resistance decreases, and they are deformed and torn; the danger is greater still, if then by the filling of the boiler, water is brought suddenly into contact with them, and transformed thus into steam under abnormal conditions. The excessive

production of steam which thus takes place is sufficient to cause an explosion.

2. The same accident may happen from the presence of incrustations left by the water upon the sides. This chemically-deposited crust prevents the contact of the water with the metal, which grows red hot, and then, if the crust happens to be detached, the meeting of the water with the red-hot surface causes a sudden and considerable production of steam, and the explosion of the boiler may be the consequence.

3. Water deprived of air and in a state of rest may be heated without boiling to a temperature far above 100° C., but the least disturbance determines a sudden ebullition, and a dangerous, because excessive, production of steam, as we have already seen in recording Donny's experiment.

The above are causes of accident independent of the good state of repair of the engine, or at least of its solidity of construction, independent also of the due care and supervision of the stoker, the first cause excepted, which is, however, one of the most frequent. The preventive measures for the latter are—attentive watching of the water level, and, if it is low, taking care not to replenish without precaution and letting down the fire; the choice of soft water, or if this is impossible, the frequent cleaning of the inner surfaces is to be recommended to stokers and managers.

4. The steam may reach a pressure above the limits of resistance if the safety valves are insufficient, work badly, or, what is worse still, although unhappily too frequently the case, if they are stopped and prevented from working at all. These apparatus ought therefore to be constantly looked to. A mechanic who fastens down his safety valves, says the celebrated engineer Mr. Fairbairn, with the energy of conviction, is comparable to the madman who throws himself into a powder magazine with a lighted torch in his hand. Ignorance alone explains so deplorable a practice, and it is the strict duty of managers and engineers to stop it by employing only competent men, and instructing those that are ignorant.

5. One more cause of explosion is the bad construction of the boiler, or, which comes to the same thing, the bad state of repair of its different parts, owing to its age or long use. We have seen in describing the different types of boilers which are those that have the least

danger of explosion, but the choice of boilers not being guided by this sole consideration, accidents are to a certain extent inevitable. It is in factories, where fixed engines are employed, and on board steamers, where the engines are exposed to more numerous causes of destruction, that explosions are most frequent and terrible; they are much more rare on locomotives, which are doubtless subject to more careful supervision. They are also less dangerous in this case, because they are often limited to the bursting of a tube, an accident which the attendant can immediately remedy by plugging it up.

CHAPTER X.

COMBINED ENGINES, HOT-AIR, AND GAS-ENGINES.

§ I.—COMBINED ENGINES.

THE principles of the mechanical theory of heat show that the value of a heat-engine, its effective power, or, which is the same thing, its *economical coefficient,* depends, other things being the same, on the difference of the extreme temperatures between which it works. It is of little consequence from this point of view, whether one liquid or another is employed to obtain the vapour whose elastic force is made use of as prime mover. The quantity of heat expended being the same, since it is this heat that is converted into work, the work done by the engine remains the same.

It may therefore be advantageous to employ a liquid which vaporizes at a temperature below that at which water boils: sulphuric ether, for example, boils at 37°. The steam, which at its departure from the cylinder passes on to be liquefied in the condenser, leaves there a quantity of heat sufficient to vaporize ether. The vapour from this latter liquid may then serve to drive a second engine annexed to the first, and whose condenser may thus be kept at a lower temperature than that of the steam condenser. This combination tends to increase the difference of the extreme temperatures between which the elastic fluid works, from its entry into the cylinder to its exit to the atmosphere or its condensations. The quantity of heat converted into mechanical work will thus be increased in the same proportion.

Such is the principle on which several combined engines are made, on which we will say a few words.

A French engineer, M. du Trembley, invented and had constructed in 1840 a combined engine for steam and ether vapour which was

fixed in one of the packets of the regular service between Marseilles and Algiers. Its principal arrangements were as follows :—

On leaving the cylinder, the steam enters a closed condenser traversed by a series of vertical tubes partly filled with ether. In condensing round these tubes, the steam gives up to them its heat of vaporization and raises their temperature sufficiently to boil the ether they inclose. The vapour of ether, collected in a reservoir above, is admitted from thence into a cylinder where it acts on a piston whose rod is attached to the shaft of the engine. The work of this piston is then added to the work of the other piston, which is moved by steam.

On leaving the second cylinder the ether vapour passes into a special condenser, also formed of a system of tubes, but these latter are surrounded by a mass of cold water constantly renewed. This vapour thus returns to the liquid state under the influence of the cooling in these tubes, and the ether thence resulting is brought back by a pump moved by the beam into a reservoir situated at the lower part of the tubes of the first condenser. The water of condensation, heated by the excess of heat in the steam, is also itself returned into the boiler.

The great inflammability of the ether, which, in spite of the greatest precautions, it was impossible to prevent escaping between the joints, rendered these engines dangerous, on account of possible explosions or conflagrations. Nevertheless they were for a long time tried on the steamboats, *Du Trembley* and *Le Galilée,* as well as in the glass works of the Guillotière, at Lyons, where an engine of this kind used to work.

A French naval officer, M. Lafont, substituted chloroform for the ether; but although the vapour of this substance is not at all inflammable, it is asphyxiating, and moreover it was proved by experience that the fittings of the pistons were quickly spoiled by its action. The attempts of which we are speaking were made in *Le Galilée* engine. Steam has also been employed in combination with the vapour of sulphur, or of perchloride of carbon.

Another very interesting engine, which was to be seen at work in the Paris Exhibition of 1867, is the ammonia engine invented by M. Frot, a marine engineer.

For the water in the boiler M. Frot substitutes a solution of

ammonia. It is known at the ordinary temperature of 15° water dissolves 750 times its volume of ammoniacal gas, and that when it is heated to 100° the gas dissolved entirely evaporates, and there is no trace of it left in the water of solution. It is on this double property that M. Frot has relied in the construction of his engine; experiments made by him on the tension of the gas at different temperatures having proved that while at 100° C. it is $7\frac{1}{2}$ atmospheres, at 120° C. it reaches 10 atmospheres. But in order to make the employment of the elastic force of ammoniacal vapours economical and practical two problems had to be solved; first to condense the vapour when it leaves the cylinder so as to obtain a sufficient difference of pressure; and secondly to re-form the ammoniacal solution, so as to use the same liquid as long as possible.

This M. Frot has accomplished without essentially modifying the arrangement of ordinary steam-engines. On leaving the cylinder, the gases, after having exercised their force on the driving piston (at which time they are composed of 1 part of steam to 5 parts of ammoniacal gas), are led into a *surface* condenser formed of a triple series of tubes round which a current of cold water is in constant circulation. In order to render the condensation quicker, the nozzle of a pump throws into the chamber which separates the two first ranges of tubes a non-saturated solution of ammonia at a low temperature, which is itself derived from the boiler. From the condenser the cooled and partly dissolved gases are brought to a reservoir called the *tubular dissolver.* There they become dissolved by contact with a non-saturated solution of ammonia, and are brought thence by a feeding pump into the boiler. During this last passage, the regenerated solution goes across some twisted tubes plunged into the liquid, which, as we have seen, serves for the injection. It here takes the heat that the latter possesses, an arrangement doubly useful, since the feeding solution enters warmer into the boiler, and the injected solution reaches the condenser cooler.

Since ammoniacal vapours attack copper, all the brass pieces of ordinary machines have to be replaced by wrought-iron. The experiments that have been made prove that the ammonia engine has several advantages over ordinary steam-engines; besides the economy of fuel, which seems to be pretty considerable, and the rapidity with which pressure is got up, we must include the almost total absence of

incrustations of the boilers after the liquid has been a long time at work; and that the ammonia preserves also the sides from oxidation. But the chief disadvantage is this, as for all combined steam-engines, the difficulty of preventing the escape of the gas; and the danger arising from a mixture with the air of a substance whose action on the respiratory organs is so dangerous.

§ II.—Hot-Air Engines.

In the engines we have just described, the motive power employed is that of the combination of steam with the vapour of a more volatile liquid, or with a gas that is forced by the heat to disengage itself from the solution. In them steam still therefore always plays an important part. An attempt has been made to substitute for it an entirely distinct elastic force, namely what we may obtain by heating a permanent gas such as air, or by setting fire to an explosive gaseous mixture, whence arise two new kinds of prime movers, *hot-air engines* and *gas-engines.* They are, however, still heat engines, for it is still from the heat employed that the mechanical work obtained.

The first attempts at employing heated air as a motive force date, it appears, from Montgolfier. One of the inventors also of photography, J. Niepce, occupied himself with the same problem. But in 1816, Robert Stirling constructed a hot-air engine, which, according to a competent authority on these subjects, is at the same time the simplest in theory and the most approved by experience.

Later, a Swedish engineer, Ericson, planned and constructed a hot-air engine which worked on board an American ship in 1853. M. Collignon defines the principle of this new prime mover in these terms:—

"In his first engine Captain Ericson placed a *regenerator* formed of a great number of metallic plates, in the path of the heated air as it left the prime cylinder when the piston was making its retrograde movement. The cylinder was heated directly by the fire, and it transmitted the motion obtained in it to a *feeding cylinder,* which was a true pump taking the air from the atmosphere and compressing it in a reservoir, whence the air reached the moving piston after traversing

the metallic sheets where it was heated at the expense of the heat given up by the hot air previously driven out."

Ericson subsequently modified his original form of steam-engine. He suppressed the metal sheets, and then the hot-air, after having worked upon the driving piston, is directly rejected from the engine. So that it is a single acting engine, and to start it the fly-wheel must first be moved by the hand. Laubereau's engine, that we are about to describe, is in this last respect similar to Ericson's, and will enable us to understand its machinery. It is, too, as simple as possible.

The driving machinery in Laubereau's engine is composed of two metal cylinders, A, B, of unequal diameter, whose interiors communicate together by a tube *t*. In the first, which is open at the top, a full sized piston, *p*, moves, which fills the cylinder hermetically and prevents any communication between the inside of the cylinder and the outer air. This is the driving cylinder and piston of the engine.

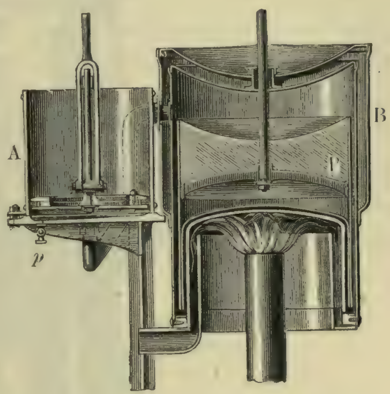


FIG. 331.—Section of the cylinders in Laubereau's engine.

The large cylinder B is completely closed at its upper and lower ends, both of which are concave exteriorly. A thick piston, P, formed of a badly conducting substance, such as plaster, also moves in the cylinder but without touching its sides. A doubly concave form is given to it in order that it may fit either end of the cylinder. This we may call the feeding cylinder, because it is the air that is contained in it, that by being alternately heated and cooled, works on the driving piston, or, on the contrary, stops that action at each period of the movement. In order to obtain these successive effects, the source of heat (in this case a jet of gas) warms the exterior concave surface of the lower side of the cylinder, and consequently the air beneath the piston P. The pressure of this air then exceeds in the larger cylinder the atmospheric pressure, and hence thrusting the piston *p* from below gives it an ascending motion which is communicated by the usual appliances to the shaft and fly-wheel of the engine. The piston P then descends again, and fits on to the lower

surface in such a way as to cut off all communication from the source of heat to the air contained in the cylinder. This air, on the contrary, is in direct contact with the upper surface of the large cylinder, which has double walls, and round which a constant current of cold water is circulating. The chilled air condenses and its

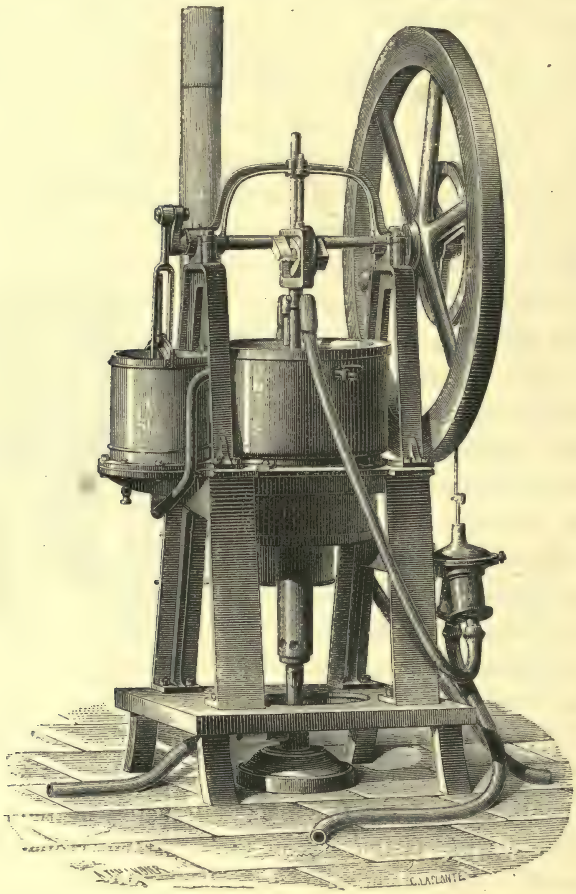


FIG. 332.—Laubereau's hot-air engine.

elastic force diminishes. The atmospheric pressure becomes the stronger, and the driving piston descends again; while, on the contrary, the plaster piston rises and exposes the air to a second heating.

This series of effects is reproduced indefinitely, and gives the

machine its constant action; a pump, worked by the driving-shaft constantly brings into the double wall of the large cylinder the cold water that is necessary for the cooling of the air that has done its work, and takes it away when heated by the heat which the air parts with to the sides of the cylinder.

The hot-air engines, &c., as well as all gas-heat engines, as distinct from steam-engines properly so-called, are useful for small operations, which require but comparatively slight power, which can be often interrupted. The ease with which they are set going makes them economical in this respect; but they would not be so for providing a continuously acting force of large amount, as in great manufactories.

Hot air has certainly one advantage over steam—namely, that between wide limits of temperature the pressures are much smaller, so that the quantity of heat consumed, and consequently work done, may be very great without there being any fear of the covering of the cylinders being deficient in resisting power; but also, practically, if a large motive force is required, the surface of the pistons must be greatly enlarged. On the other hand, at high temperature, the hot air burns the fittings of the pistons, and oxidizes and spoils the metallic surfaces with which it comes into contact. Steam has none of these disadvantages.

§ III.—Gas-engines.

We now come to some other prime movers which are beginning to be employed pretty frequently in small operations—we refer to gas-engines.

It is still the expansion of air that supplies the motive force to these machines; but instead of being expanded by the action of a source of heat maintained beneath the chamber containing it, it is by the effect of the disengagement of heat produced by the explosion of an explosive mixture. This mixture is formed of air and illuminating gas in suitable proportions.

The different methods of producing this explosion have given rise to various arrangements of the gas-engines. In Lenoir's engine, the explosive mixture formed of twenty parts of air to ten parts of gas is kindled by the successive sparks of an induction coil. In Hugon's

engine a movable gas-jet fires the mixture; in Otto and Langen's engine the gases are also kindled by a lighted jet, but in this case a fixed one. We will rapidly examine the essential arrangements of each of these prime movers.

Lenoir's engine only differs, as far as external aspect is concerned, from a steam-engine in the absence of a boiler and the particular arrangement of the distributing machinery.

The driving cylinder is a pump body of large diameter, resting

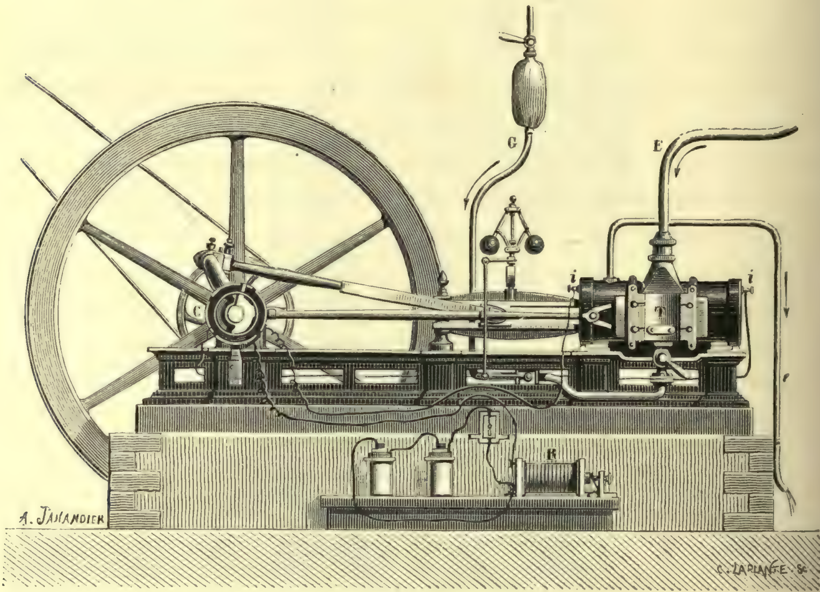


FIG. 333.—Lenoir's gas-engine.

horizontally on the framework of the engine; and its rod gives the motion, by means of connecting rod and crank, to the shaft, on one side of which is fixed the driving-pulley, and on the other a fly-wheel. The cylinder is flanked on the side by two slide-valves, moved by eccentrics; one of them is for introducing the explosive mixture of air and hydrogen coming by the piston (pipe) G on the two sides of the driving-piston alternately, and the other for letting the products of combustion escape.

On the framework of the engine a Ruhmkorff's coil is fixed, which is worked by a Bunsen battery. This furnishes the successive sparks

for kindling the gaseous mixture in each of the chambers of the cylinder. For this purpose the wires of the induction coil end respectively in *i i* on one of the metallic ends of the cylinder, which they penetrate by an insulating rod of porcelain; the spark flies from the piston to this platinum wire. The explosive mixture which enters the chamber at the same instant, owing to the motion of the slide-valve, is successively kindled. The heat resulting from these successive explosions is communicated to the air, and by expanding it furnishes the motive force. At the same time the other slide-valve lets the gas produced by the combustion, and which is now in the other chamber, escape; whence the alternating motion of the piston and the motion of the shaft and fly-wheel. Since the sides of the cylinder are heated at each explosion, and in order to avoid the high temperature which would often be the consequence, they are surrounded by a case in which a current of cold water is continually circulating; this current arrives by the tube E and leaves by the tube *e*.

Hugon's engine chiefly differs, as we have said, from Lenoir's, by the method of exploding the gaseous mixture. Instead of induction sparks, a jet of gas is brought by the motion of the engine itself first into contact with the mixture, and then away from it.

In this respect Otto and Langen's gas-engine resembles Hugon's; but it differs from it as well as from Lenoir's in an essential point. This engine, as improved by Crossley, works by the vacuum resulting from the explosion of common coal gas and air; the piston is not, as is usual, connected with the shaft on both up and down stroke, but on the down stroke only. It is thus at liberty to fly up freely from the force of the explosion, which takes place at the bottom only, and by driving the piston before it empties the cylinder of air through its open upper end. The return of the air on the down stroke yields the driving power, and turns the shaft by means of a friction clutch, to which the piston is geared by the rack. The vacuum beneath the piston is equal to about eleven lbs. per square inch for the greater part of the down stroke. The governor does not act, as is usual, by increasing or decreasing the power of each stroke, but by varying the number of strokes, each being of the same power. This is done without materially changing the speed of the shaft. Three or four explosions per minute are generally sufficient to turn the engine itself, and as a maximum of thirty to thirty-five may be made there is a

balance of, say, from twenty-six to thirty-two strokes or explosions per minute left to be applied to useful work under the regulation of the governor. As this engine can be started and stopped at a moment's notice, giving full power at once, and is free from the risks of a boiler explosion, it is peculiarly suited for use as a motor in a laboratory. The consumption of gas is seldom over 2*s.* 6*d.* worth per per week for a one horse-power engine.

From a theoretical point of view, gas, and hot-air engines (they are both founded on the same principle), should—as we said at the commencement,—have this advantage over steam-engines, that the temperature of the gas may attain to a much higher value, without giving more than a comparatively feeble pressure. Since the mechanical work depends only on the difference between the extreme temperatures, it follows that a larger part of it may be used for work without fearing accidents from explosion. For the same amount of power the sides of the different parts may be thinner; but on the other hand, we have seen also that a too high temperature in the gas has a destructive effect on the fittings and metallic parts. The advantages therefore are in great part counterbalanced by this serious drawback.

But gas-engines have an incontestable superiority over steam-engines so far as regards security; they are almost entirely free from any possibility of explosion, or fear of fire. It is easy to put them in action and requires but little time: they may be set going or stopped by the simple opening of a tap. Having neither grate nor boiler, they are less cumbersome and require much less personal attention for working and overlooking.

Economically speaking they are, on the contrary, inferior to steam-engines. It follows indeed from experiments made by M. Tresca on the Lenoir engine that the consumption of gas is 2,500 to 3,000 litres for each horse-power per hour, which is five or six times the expense in fuel of the steam-engine. It requires also a great expense in water for cooling the driving cylinder and piston. Otto and Langen's gas-engine is much more heating than Lenoir's, which has however the same fault to a certain degree, and the sudden motions of the piston must be a quickly acting cause of deterioration. All gas-engines have also this inconvenience, that they can only be used where gas is to be had; and it is in gas houses that the disadvantages of steam-engines

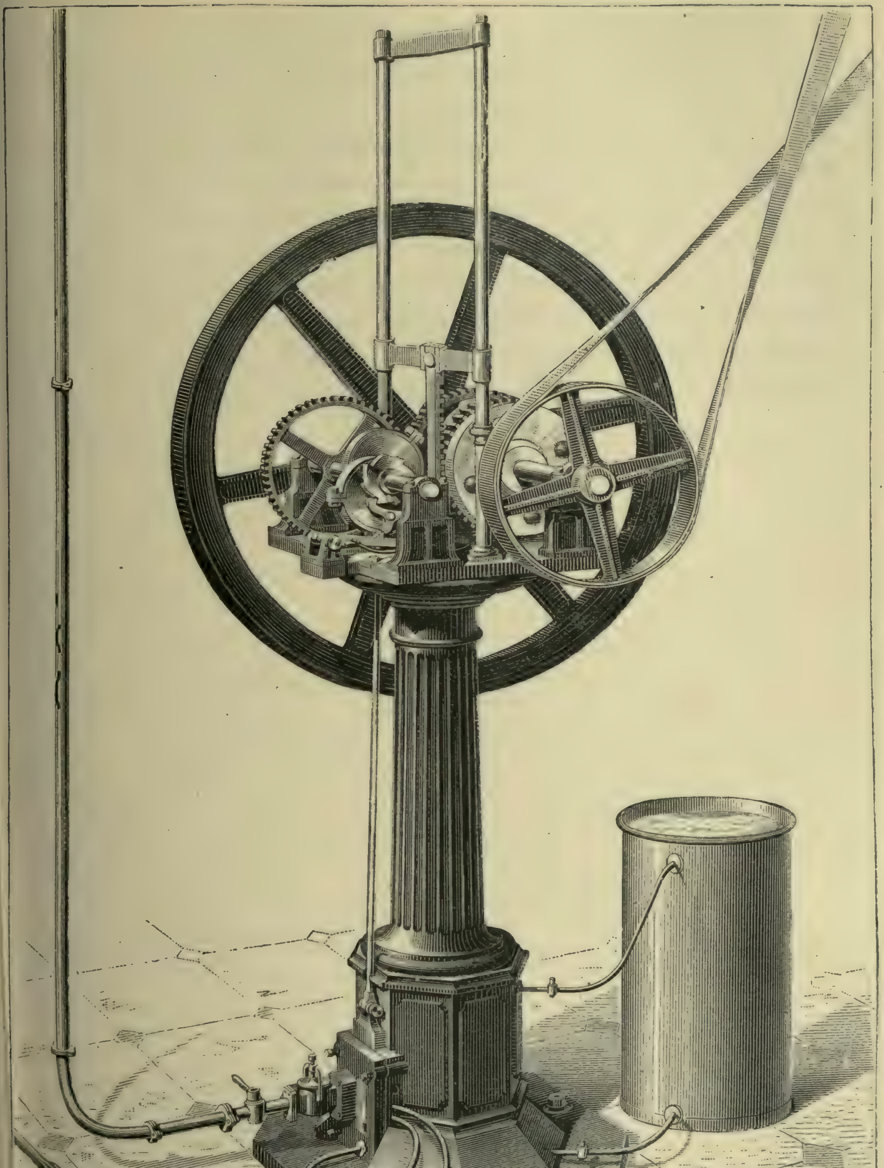


PLATE XVIII.—OTTO AND LANGEN'S GAS-ENGINE.

are found. But if we consider the use of gas-engines for a limited application—that is, for small operations, where the motive force required is not above a few horse-power, they will then be found superior even from a relatively economical point of view. They adapt themselves indeed to all the requirements of stopping and frequent recommencing of work, when the expense stops at the same moment; while steam-engines, when once lighted and set going, consume fuel all the time they are doing no work. From this point of view hot-air and gas-engines have a real interest, and they will render great service if, in addition, as is not unlikely, they receive improvements comparable to those that have been made in the steam-engine.

BOOK V.

MAGNETISM AND ELECTRICITY.

BOOK V.

MAGNETISM AND ELECTRICITY.

CHAPTER I.

THE COMPASS.

§ I.—The Declination Compass.—Its Uses.

LONG before the laws of magnetic phenomena were known, the compass was used to navigate the open sea, when the sky, concealed by clouds and fogs, gave no astronomical indication of the direction the ships should follow. It is one of the most striking examples of an application of physical phenomena long before the discovery of the laws or the theory. "A thousand years and more, before our era," says Humboldt, "and at so obscure a time as that of Codrus and of the return of the Heraclides to the Peloponnesus, the Chinese had already their *magnetic balances*, one arm of which carried a human figure which always pointed to the south; and they made use of this compass to direct them across the vast steppes of Tartary. In the third century of our era, that is to say, seven hundred years at least before the introduction of the compass to the European waters the Chinese junks navigated the Indian Ocean by the pointing of the magnet to the south."

The *south-pointing chariots* of which Humboldt speaks consisted of a little statuette turning on a vertical pivot, one of whose outstretched arms pointed to the south because it contained a magnetic needle of which the south-seeking pole was towards the hand, while

the north-seeking pole was towards the shoulder. Afterwards, in the second century, the Chinese compass had another arrangement which, through the Arabs, was communicated to European navigators at the time of the first crusades. This was a magnetic needle on a floating support. It was not till towards the first half of the fourteenth century that this instrument, so useful in navigation, so precious in these days for the physical study of the globe, received a new improvement, and the magnetic needle was supported on a pivot.

Without stopping too long on the history of the compass and its application to navigation and the arts and sciences, we will rapidly pass in review the laws of magnetic orientation, and describe the apparatus as they are now employed for various purposes.

A magnetized needle freely suspended by its centre of gravity, and free to oscillate in every direction about that point, takes, when it is in equilibrium, a position which makes an angle both with the meridian and with the horizon of the place. The first is called the angle of declination, or simply the *magnetic declination;* the second is the *magnetic inclination,*—whence there are two kinds of compasses, according as it is intended to determine the one or the other of these physical elements.

We shall first deal with the Declination Compass.

When a scientific determination is required, the declination compass is constructed as in Fig. 334. The magnetized needle is supported on an agate pivot, and inclosed in a cylindrical case M which carries on two metallic mounts a telescope L L′, provided with cross wires at its focus and movable itself about an axis $a\,a'$, parallel to the plane of the instrument's edge. All this system can itself turn horizontally upon this plane which is bounded by a divided circle P Q.

To measure the declination the compass is placed on a nearly horizontal surface, and its perfect horizontality is secured by observing the spirit-level $b\,b'$. This done, the telescope is turned to a known star, and from the time of the observation, the angle may be calculated which the vertical plane containing the star and the telescope makes with the meridian, which is called the star's azimuth. From this the direction of the meridian is fixed on the edge P Q. The inner rim is then turned on the circle P Q by a quantity equal to that angle; the line of vision N S, 0°—180°, is then on the meridian, and it only remains to read upon the circle M the angle which it makes with the

magnetized needle. This angle is the magnetic declination of the place at the moment of observation.

The same method of observation is employed in measuring the declination by means of Gambey's compass (Fig. 335), only this instrument enables us to obtain the element in question with a *still greater precision.* The needle here is a magnetized bar A B, whose ends are provided with two rings with cross wires which serve to fix the position. This bar supported in its centre by a stirrup is suspended by a fine bundle of silk threads without torsion to a movable windlass. Under the influence of the earth's magnetism it takes up after a few oscillations a fixed direction, which is that of the magnetic meridian of the place at the moment of observation. The whole question consists in determining with all the precision possible the angle which the magnetized bar then makes with the geographical meridian of the place. The frame which supports the stirrup carries at the same time a telescope L, which fulfils the same office as that of the compass described above. The frame which supports it, and which supports also the suspending thread and the bar, turns on the plane of the divided edge C C, provided with verniers by which to read the divisions corresponding, first to the position of the telescope, and consequently to that of the vertical plane of the star observed, and then to the position of the vertical plane containing the axis of the magnetized bar. In order to avoid the influence of the motions of the air, the silk thread is inclosed in a case with glass sides, and another case, M M, incloses the bar, whose extremities are then observed through the openings O O.

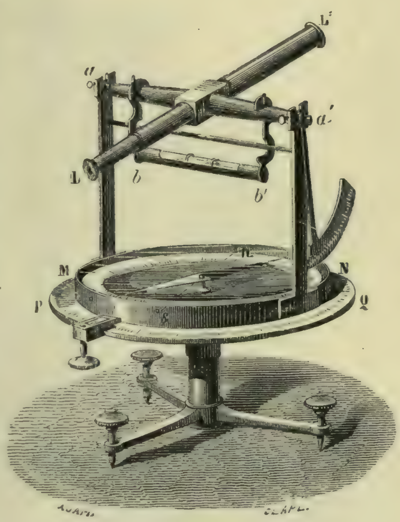


FIG. 334.—Declination compass.

The declination compass is of the greatest use to navigators, in furnishing them with one of the elements necessary for determining the route of the ship, that is, the angle which the vessel's course

makes with the meridian of the place it is in. In sailing by reckoning, the other element, determined by means of the instrument called the *log*, is the speed of the ship.

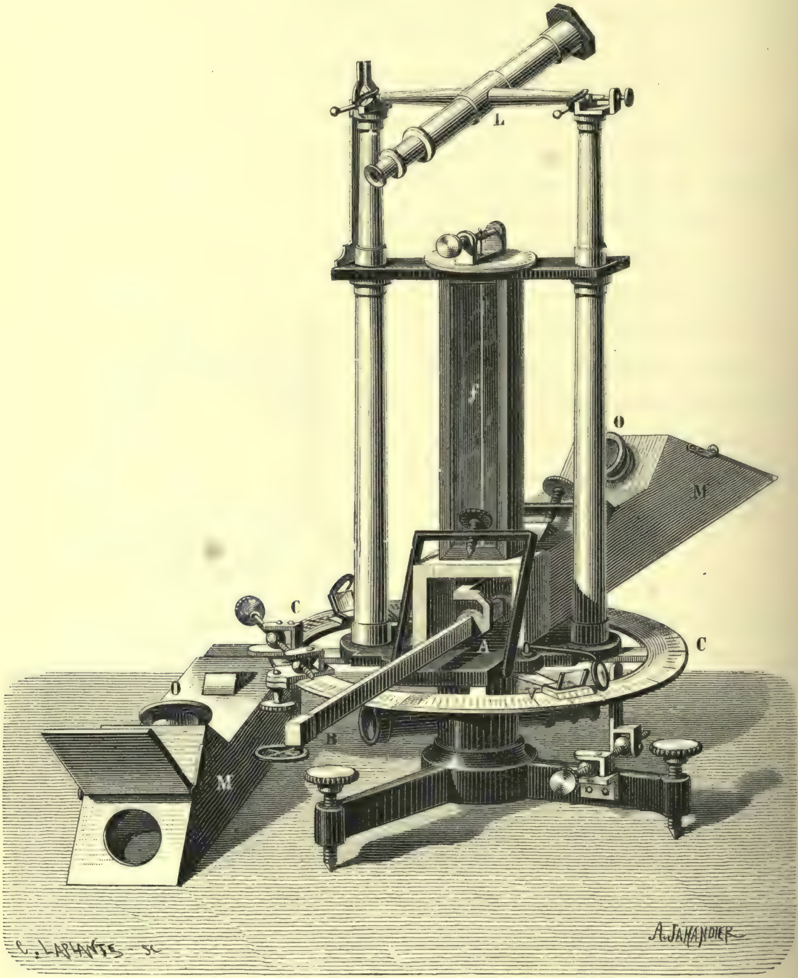


FIG. 335.—Gambey's declination compass.

The compass thus used is spoken of by sailors as the ship's compass. It is fixed abaft near the wheel, in a sort of protecting box called the binnacle. The binnacle is generally divided into three compartments, one in the middle containing a lamp for taking

observations by night, the other two contain each a compass, so as to be under immediate control.

In the ship's compass the magnetized needle rests on a pivot in the centre of the compass-box, or cylinder of copper. It carries a light disc, or compass card, on which are drawn the various points, and which also makes the oscillations smaller. The compass-box, weighted by a mass of metal, is itself carried in the binnacle by means of Cardan's suspension, or gimbals: so that the plane of the card remains horizontal whatever may be the movements of the ship.

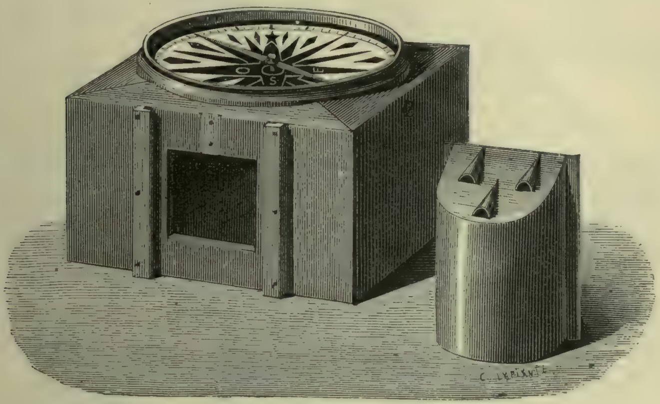


FIG. 336.—Ship's, or mariner's, compass.

A mark or a star on the compass-box in its front side shows the direction of the axis of the ship; this point is called the head of the compass.

At any moment the angle which the magnetized needle makes with the head of the compass can be read on the compass card. By adding to this angle the magnetic declination, or by subtracting it, as the case may be, the true orientation of the ship is found.[1]

[1] The employment of the compass for navigation or geographical exploration supposes, as we have just seen, the knowledge of the value of the magnetic declination of the places where the sailor or the traveller makes his observations, but it is essentially necessary that there should be no disturbance close to him, that would introduce an error—of all the more importance as he believes himself protected from it. Now that the number of ships whose hulls are wholly or in part built of iron, goes on increasing, a similar cause of error exists in effect in the ship itself; and it appears certain that the deviation of the magnet on vessels so constructed

A compass is also used in the navy, which has for its object the determination of the magnetic declination by an operation exactly similar to that described above. A known star is observed, its azimuth measured, which gives the direction of the meridian, and thence

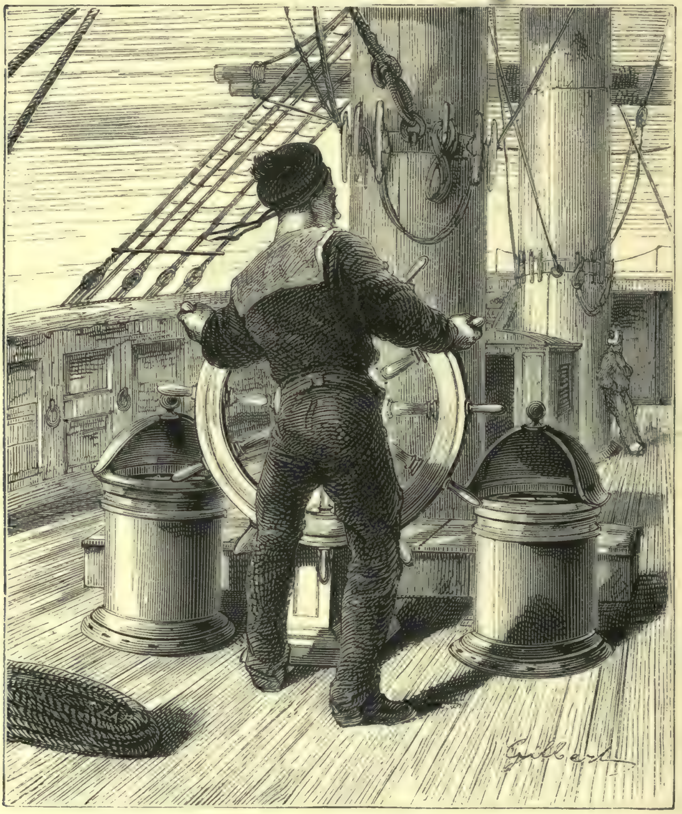


FIG. 337.—The binnacle of a man-of war.

the declination is obtained. The compass is called a variation compass. It is portable, like the compass in Fig. 338, and only differs

has been the principal cause of many misfortunes. When the bolts of an iron hull are driven home, a powerful magnetism is developed, a magnet is formed whose direction depends on the direction of the axis of the ship while in course of construction. This magnetism acts on the needle of the compass afterwards fixed abaft, and produces a deviation which must be calculated or defined, in order to avoid errors of observation. By placing a standard compass in another part of the ship the

from it essentially in having the telescope replaced by a concentric sight-vane with pinules PP′ at opposite extremities of a diameter. The case containing the magnetic needle with divided edge is suspended on gimbals. Two wires crossing at right angles are stretched over the side of the case containing the needle, and one of them gives the direction of the slits in the pinules, and consequently that of the plane of vision. One of the pinules carries a mirror at an angle of 45°, in which the observer sees the arc of the card and the corresponding divisions at the same time that he sees the star through the slit of

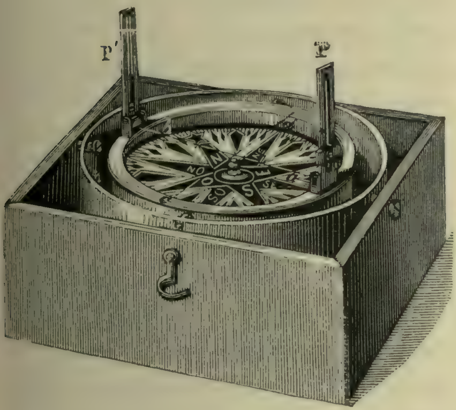


FIG. 338.—Variation compass.

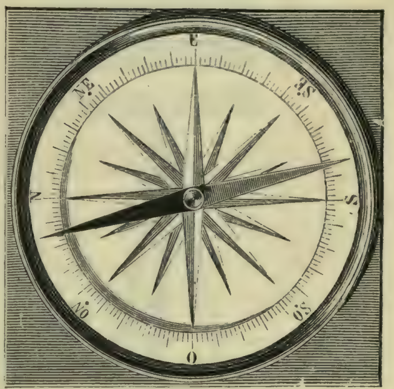


FIG. 339.—Portable declination compass.

the pinule and a part of the mirror where the quicksilver has been removed.

While one observer sees the star, planet, moon, sun, or a terrestrial object, and reads by the mirror the division which shows the angle that the magnetic needle makes with the vertical plane of the object seen, another observer makes a second reading by means of a thread, which is stretched at right angles to the direction of the pinules; this second reading serves to control the first. With this instrument those

necessary correction may be made ; or another means may be employed, that of placing, in convenient places, bars of soft iron or magnets calculated to destroy the deviation. Unfortunately, it happens, that during the voyage, the magnetism of the ship changes in direction and intensity,—and then the risk is so much the greater as there is believed to be none.

We have here a most interesting problem, of which the solution is still being studied

objects only can be seen that are not much above the horizon—at greatest 12° to 20°.

The variation compass is sometimes placed on a platform above the dome over the after-cabin stairs.

Travellers in their geographical explorations of the interior of continents, and geologists who wish to know the directions of mountain chains, or of the other surface features, employ the compass like sailors. Only as the instrument is more easily set up in a fixed position there is no need for so complex a method of suspension. It is enough to have a tripod stand, to which the compass is fixed by a ball and socket joint, and a spirit level to secure the horizontality of the reading circle. A small telescope, with cross wires, which moves parallel to the north and south line on the compass in a vertical plane, enables the observer to look in the direction of the line whose orientation has to be measured. The more simple compasses have a sight-vane with pinules instead of a telescope.

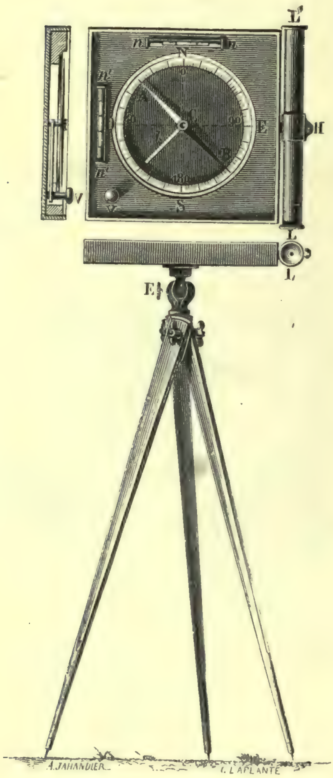


FIG. 340.—Surveying compass.

Since the compass enables us, when the magnetic variation of a place is known, to find rapidly the angle which any line makes with the meridian—that is its orientation—it is clear that if we have determined in this way the azimuthal angles of a series of horizontal lines, say those of the sides of a polygon, it is only necessary to take the difference between these angles in order to obtain the angles which these lines make with each other; and more than this, if we only require to know the angles of the polygon, they may be obtained in the same way, without our being obliged to know the declination of the place. It is sufficient that during the operation the direction

of the needle should remain constant, which is sufficiently the case during the ordinary time occupied in topographical operations. Such is the principle of the employment of the compass in land surveying. But the measurement of the angles by this means is not sufficiently exact, if it must be within half or a quarter of a degree; the oscillation of the needle, which makes it difficult to read the angle, and the diurnal and irregular variations of the declination, which are sometimes considerable, are the principal causes of this defect in precision.

Compasses have been constructed for the purposes of military reconnoitring, which do not give even so good an approximation as this, for the very simple reason that instead of being fixed they are only held in the hand in making an observation. We only mention them to call to mind this application of the declination compass.

§ II.—Dip Circles.—Terrestrial Magnetism.

The dip circles, or inclination compasses, have for their object the measurement of the angle which the magnetic needle makes with the vertical of the place. Since this element is only susceptible of application in physical researches on the earth, we shall confine ourselves to describing succinctly the dip circle adopted in magnetic observatories.

A metallic divided circle, in the centre of which a magnetic needle is suspended so as to turn freely in the plane of the edge; another circle similarly divided, and supported on a stand with three levelling screws—such are the two principal parts of the apparatus represented in Fig. 341. By means of a spirit level the second circle may be placed in a perfectly horizontal plane. In this case the first circle, which is perpendicular to the other, is vertical. It can also turn with its support about the axis of the instrument, and allow the needle to be placed in the magnetic meridian—a sight-vane movable with the support serves to fix the position.[1] In this position the

[1] This position may be found if to the apparatus we adapt a declination compass. But this is not required, since all we need do is to find the position of the vertical circle in which the needle at rest is vertical. The magnetic meridian makes an angle of 90° with this position. By turning the vertical circle through 90°, we know then that we have placed it in the magnetic meridian.

needle comes to rest after certain oscillations inclined to the horizon at an angle which may be read off on the graduated circle. It is this angle that measures the magnetic dip at the time and place of observation.

It remains to say a few words about an important application of the declination and inclination compasses—we mean the scientific determination of these two elements and their diurnal, annual, and secular variations at different points of the earth's surface. It is a most interesting line of research, and at the same time of the greatest use in navigation and geography.

The study of the magnetism of the surface of the globe has shown that the declination, the inclination, and the intensity change from one place to another in a pretty continuous, but very irregular, manner in relation to geographical positions. To represent the state at a given time Humboldt conceived the happy idea of drawing on terrestrial globes or charts three series of lines. The isogonic lines are curves joining all the points which have the same easterly declination or the same westerly declination. The isoclinic lines similarly indicate the places on the earth where the dip, either to north or south, is the same; and lastly, a third series is composed of isodynamic lines, that is, the chains of points on the globe where the intensity of the force of terrestrial magnetism has the same value. It appears from an examination of these lines that there are in the neighbourhood of the two geographical poles two points to which the isogonic lines converge, and which are the common centres of the isoclinic but not of the isodynamic curves. These are the magnetic poles of the globe. At these two points the declination compass is indifferent, while the needle of the inclination compass there maintains a constantly vertical direction. As to the isogonic lines, not

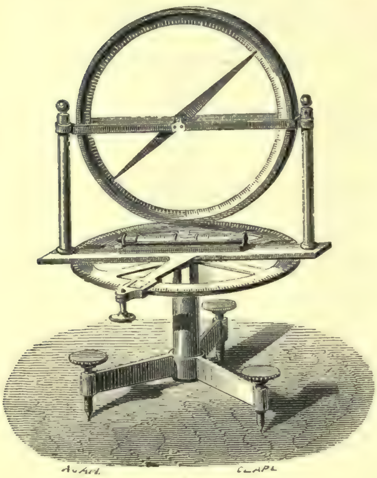


FIG. 341.—Dip circle.

only do they not coincide with the geographical meridians, but they must be distinguished also from the magnetic meridians. Among them two are remarkable, namely, the lines in which the declination is zero, which may be regarded as the continuation of each other; one crosses the American continent from Hudson's Bay to South Carolina, from the mouth of the Amazon to Rio de Janeiro; the other, less regular, cuts Australia, curves to the west of India, and passes by the Caspian Sea and the Aral Mountains to the White Sea. The two lines of no declination divide the globe into two parts; that which contains Europe and Africa has all its declinations to the west, while those of the other part are all to the east. There exists in Asia an isolated elliptical portion of a line of no declination which surrounds a space in which the declination is to the west.

The magnetic equator is the line of points where the needle of the dip circle remains horizontal, and for which consequently the inclination is zero. It does not coincide with the terrestrial equator, which it cuts in two points and touches in a third. The first two points are in the Gulf of Guinea, and in the Pacific Ocean about west longitude 175° or 180°, and the point of contact is in Polynesia, about 135° west longitude from Paris. The isoclinic lines follow pretty nearly the contour of the magnetic equator, thus differing very sensibly from the geographical parallels.

These systems of lines are not permanent, because the magnetic state of the earth is subject to certain oscillations of which some are periodic, and others variable. The declination, inclination and dynamic intensity vary continually in each place, and from place to place on the surface of the globe. These variations are partly secular, partly annual, and partly diurnal. For example, at Paris, the value of the magnetic declination, which is now about 18°, and is to the west, was nothing in 1663, that is, a little more than two centuries ago; before that it was to the east; for example, in 1580 it was 11° 30′ E. Since 1663 it increased continually to the west till 1814, when it attained its maximum. Since then it has been going back. The dip has varied in like manner since the earliest observations. It was 75° at Paris in 1671, it is now only 66°; this, however, is a much less marked variation than that of the declination. Independent of these variations of long period, terrestrial magnetism is subject to annual ones, which appear to depend on the position of the sun relatively to

the equator; it is also subject to diurnal variations, which in Europe draw the north-seeking end of the needle westwards from sunrise to one or two o'clock in the afternoon, and bring it back again towards its original position till ten o'clock at night. The amplitude of these variations oscillates between five or six minutes and twenty or twenty-five minutes.

The perturbations or irregular variations of terrestrial magnetism consist in sudden changes which show themselves in the position of the needle of the compasses. Some are very evidently connected with natural phenomena, such as the aurora borealis, and possibly the eruptions of volcanoes, and the shocks of earthquakes; others are from unknown causes.

We do not enter further into details on this interesting subject which is to be found developed in original memoirs and in works on physical geography. Our object has been to point out the importance of its applications.

CHAPTER II.

LIGHTNING-CONDUCTORS.

§ I.—The Principles on which Lightning-conductors are Constructed.

ARAGO in his admirable *Notice sur le Tonnerre* passes in review the various processes to which, from ancient times to that of Franklin, or even of ourselves, popular prejudice and the prejudice of men of science attributed the property of dissipating the clouds and escaping the lightning. A great number of these processes were only practices originating in superstitious credulity, and need not be mentioned. Some were founded on hypotheses not justified by experience, or as to which observation has hitherto furnished contradictory results. For example, it has been thought that great fires kindled in the open air took away from the clouds, at least in part, their fulminating properties. It was the opinion of Voltaire, based no doubt on the experimental fact that flames and hot gases are good conductors of electricity. But in the case of fires kindled in the open air could the gaseous columns rise to a sufficient height to reach the thunder clouds? Anyhow, we have heard of places where the peasants have been in the habit of lighting, on the approach of storms, heaps of straw distributed here and there on the fields, and these places have not in fact suffered from lightning or hail. But on the other hand great conflagrations have happened a little before or during great storms, without the clouds which were nearest even to the scene of the accident having been deprived, to all appearance, of the smallest part of their electricity. The efficacy of this method is therefore at least doubtful.

Another means of dissipating clouds of every kind, and consequently storm clouds, has been pretty frequently employed by sailors and agriculturists. It is that of firing off pieces of artillery, cannons, or other firearms. But the very precise examples cited by Arago for

and against this method, prove that it is far from being certainly efficacious. It is not even proved that it has ever had any influence at all in dispersing clouds, and one might just as easily deduce the opposite conclusion from the facts stated.

The same must be said of the ringing of bells. The practice of setting the church bells ringing during storms has no other origin than in superstition, and the most certain effect of the practice of it is to make the ringers run a real danger, in order to ward off a much smaller one by imaginary means. Lightning, in fact, strikes by preference the highest objects, especially those which, like bell towers, are almost always surmounted by insulated metal.

Since the time of Franklin, who was, as is well known, the inventor of lightning-conductors, science can recommend no other means of preserving edifices and houses with their inhabitants from lightning than these simple and almost always sufficient apparatus, provided they be constructed and set up in such a way as experience and theory unite in regarding as correct.

The lightning-conductor is an application of the power possessed by metallic points of discharging the electricity from bodies in their neighbourhood, and the idea of making use of this property, which the illustrious American physicist had lately discovered, was the natural consequence of his opinion on the identity of lightning and thunder with electrical phenomena. The experiments which proved this identity were made almost simultaneously, in 1752, in America and in France, Franklin flying in that year his famous kite, armed with a point, and drawing sparks from a thunder cloud near Philadelphia, whilst the French physicist Dalibard verified at the same time the ideas suggested by Franklin by setting up an insulated bar of iron fourteen metres high in the plain of Marly-en-ville.

Shortly afterwards the first lightning conductors were fixed at Philadelphia. From America they quickly passed to Europe, and the first one seen in France was fixed at Dijon by Guyton de Morveau.

The most recent [1] instructions on the employment and construc-

[1] The first report upon this interesting question dates from 24th of April, 1784, and the commission which drew it up numbered among its members Coulomb, Laplace, and Franklin himself.

In 1799, 1823 and 1855, new instructions were given and submitted to the approbation of the Academy of Sciences.

tion of lightning-conductors come from a commission of the French Academy of Sciences, which reported on the 14th of January, 1867, through M. Pouillet. Our description will be founded on this report.

We commence by explaining the theory of storm-clouds and that of the action of the lightning-conductors on the electricity they contain.

1. Storm-clouds which produce lightning are nothing else than ordinary clouds charged with a great quantity of electricity.

The lightning which cleaves the sky is an immense electric spark, whose two poles are the two clouds, separated from each other and charged with opposite electricities.

The thunder is the noise of the spark.

The lightning is the spark itself, or the recombination of the opposite electricities.

When one of the poles of the lightning is on the surface of the ground we say that the thunder, or rather the lightning falls, and that the terrestrial objects are struck by lightning. Then all the points of the tongue of lightning are still the recombination or neutralization of the two opposite electricities, one of which is furnished by the cloud and the other by the earth itself.

How comes the earth, which is generally in a natural state, and without apparent electricity, to be thus charged with electricity, and that contrary to the electricity of the cloud at the very moment it is struck?

This is the first question we have to examine.

2. Before the lightning falls the storm-cloud that contains it, notwithstanding it is several furlongs above the ground, acts by induction to repel the electricity of like kind, and to attract the electricity of the opposite kind. This induction tends to influence all bodies, but it is really only effectual on good conductors; such are, in different degrees, the metals, water, moist earth, living creatures, vegetables, &c.

The same conductor experiences very different effects from the cloud, according to its own form and dimensions, and above all according as its communication with the ground is perfect or imperfect.

A tree, for instance, when it stands in ground only moderately moist is but little influenced by induction, because the electricity of

the same kind cannot be repelled far through this ground, because it is but a very bad conductor for large charges of electricity.

If the tree, on the contrary, is on very wet ground of great extent, it will be much influenced, because the electricity of the same kind can spread a long way in this good conductor, and the whole amount of possible induction will take place, if this good conductor, at its limits, is also in communication with other sheets of water of indefinite size.

When we are dealing with the electricity of our machines, the surface of the earth, whatever it may be, is what we call the ground or the common reservoir. We can call it so, because its conductibility is sufficient to disperse and neutralize all our little electrical charges.

When we are dealing with lightning, the vegetable soil, in its usual state, is not what we can call the common reservoir, it becomes relatively a bad conductor, according to the geological formations of various kinds on which it reposes. It must reach the first water-bearing stratum, that is the stratum supplying wells which never dry up (we will call it here the subterranean stratum), to find a bed whose conductibility is sufficient. This, on account of its extent and numerous ramifications, cannot be insulated from the neighbouring water-courses; and with them, the streams and rivers, and the sea itself, it constitutes what we may call the common reservoir for thunder-clouds, and consequently the common reservoir for the lightning-conductors.

"In fact, while the storm-cloud exercises its induction everywhere below it, attracting the contrary, and repelling the like electricity, the subterranean stratum is affected by the induction to an incomparable degree. Then all the upper surface becomes charged with the opposite electricity which the cloud accumulates there by its attraction, while the electricity of the same kind is repelled and dispersed at a distance in the common reservoir. So when the lightning falls the two poles are one on the cloud and the other on the subterranean stratum, which acts as a second cloud necessary for the explosion of the lightning.

"It is in this way that the globe, always on the whole in a natural state, is eventually electrified at certain points by the presence of the storm-clouds.

"Buildings, trees, and living animals, which are struck by lightning

must be considered as simply media which it finds in the way and strikes in passing.

"At the same time we must not hence conclude that these media are essentially passive, and never contribute in any way to modify or even to determine the direction of the lightning-stroke. It is certain, on the contrary, that they exercise in this respect an influence which is all the greater, as they are of more considerable size and of better conducting power. When a vessel, for example, is struck in the middle of the sea, it is very probable that the lightning has not taken the path which would be geometrically shortest to reach the water it is seeking, and where it will be neutralized by the opposite electricity, but that it has chosen the way that was electrically the shortest, on account of the decomposition by induction which the cloud has previously produced, on the masts, rigging, and other conductors of the vessel, which are more or less elevated and good conductors.

"This phenomenon is analogous to that of the spark drawn at a great distance between the conductors of a powerful electrical machine; it may be turned aside from its most direct path by the presence of one or more insulated conductors placed near its line of traverse; it passes to strike the same point, but it reaches it by a path electrically shorter, although it is longer in appearance.

"Here the insulated conductors change the direction of the spark. The media, of which we spoke just now, change the direction of the lightning. We limit ourselves to the simple enunciation of this fundamental principle which we cannot develop here: it contains the explanation of all the movements, often so strange, of strokes of lightning and of all the destructive effects they produce. We can never account for them without having thoroughly recognised the two poles or points of departure, and between these two points a series of media which have been struck by the fork of the lightning, sometimes single sometimes multiple."

Here ends the theoretical part of the report, which in the opinion of the members of the commission, serves as a base for those practical instructions afterwards laid down for the construction and fixing of lightning-conductors. We now return to these instructions as far as they are essential.

§ II.—Description and Arrangement of Lightning-conductors.

A lightning-conductor is nothing else than a good conductor without interruption, the upper end of which is raised to a sufficient height to command the edifice it has to protect, and the lower end communicates freely with a subterranean water-bearing stratum.

As lightning can melt and volatilize metallic threads of a small diameter (less than six millimetres), but has never been known to bring even to a low red heat, square rods of iron fifteen millimetres in the side, the conductors should be made of not less dimensions than this.

The lightning-conductor is composed of two principal parts, the rod and the conductor or conductors; the description of which is now given.

The iron rod which forms the upper end should be terminated by a cylinder of red copper of 2 centimetres diameter and of 20 to 25 centimetres in length, fixed by a screw to the rod. This cylinder is itself terminated at the top by a cone. The lower part of the rod is square, and gradually increases in thickness to the point of junction with the conductor, where the section measures about 4 or 5 centimetres on the side. In this case the total height of the rod varies from 3 to 5 metres. Formerly it was recommended to terminate the rod by a fine and very sharp point of gold or platinum. When this was done as soon as the storm commenced the electricity passed away through the point in the form of a luminous brush visible in the dark. The highly electrified air in passing to the cloud neutralized, it was thought, a portion of the electricity of the latter. But the intensity of the electric flow was sufficient at the same time to melt the gold or platinum point, so that after a certain time the sharp point disappeared and was replaced by a large button of fused metal.

The preventive action of the sharp point in drawing off the electricity in the form of a luminous brush, was only assured for a limited time; besides this, it was not a very great advantage, if it were true that the air electrified by the rod instead of going directly to the cloud was often driven away laterally by the wind. For these reasons the preference is now given to rods ending in a cylinder and cone of copper. Formed in this way the point of a lightning-conductor very seldom

shows any luminous brushes, but on account of the form and the great conductivity of copper—it resists fusion much better, without being any the less effective a protection to the building. The essential thing

FIG. 342.—Conical point of red copper in the lightning-conductor.

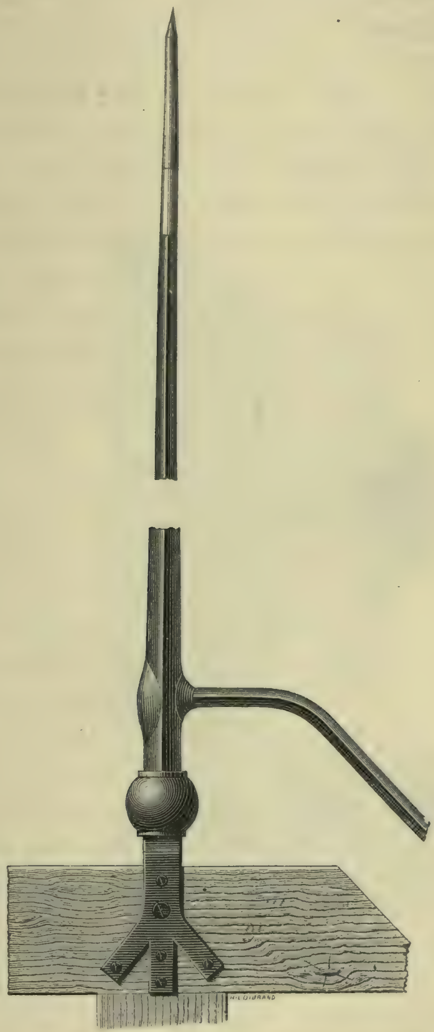


FIG. 343.—Vertical rod of the lightning-conductor.

is that the electrical current in passing from the cloud to the lightning-conductor, when the lightning falls should find an uninterrupted path from the point to the subterranean stratum.

The metallic bar which serves as the conductor, and has, as we have seen, a section of about 15 millimetres in diameter, must be soldered with care to the rod which is itself firmly fixed to the framework of the ridge of the building. All the successive parts, whether vertical, horizontal, or inclined must be joined by curves and soldered with the same care at the points of junction. The constancy of these junctions is further secured by branching iron supports which allow of a longitudinal motion, without any lateral swaying.

The rigid bars of the conductor are sometimes replaced by cables of three or four strands of iron wire, tarred outside to prevent rust. Great care must then be taken that the communication of the cable with the rod shall take place by as large a contact as possible between the metallic surface of the rod and the iron wires; these must be perfectly clean and soldered to the iron of the rod.

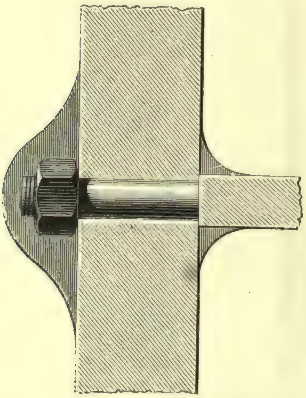


FIG. 344.—Junction of the vertical rod to the conductor.

An essential condition, too, is that all the metallic parts of the building, the ridges and gutters of lead or zinc the beams and floors of iron should all be in communication with each other and with the lightning-conductor.

We now come to the most essential condition of all, which, if neglected, would make the lightning-conductor, instead of being a protection against the lightning, a very dangerous apparatus on the occasion of a storm. It is that the conductor having once reached the ground should go deep enough to be in constant communication with a water-bearing stratum. For this purpose a well may have to be sunk on purpose, of such a depth that in the greatest droughts the water may stand in it to the height of a metre at least. If any water-courses, streams, or rivers, of sufficient size to be never dry in times of drought, or if lakes or large ponds happen to be near the conductor, it is sufficient to put it in constant communication with the water.

Besides this, there is no reason why the conductor should not also be placed in communication with the upper layer of the soil which forms a supplementary reservoir when sufficiently saturated with rain ;

but this precaution would be quite insufficient if it were not combined with the principal one of a well into which the conductor dips by several branches, as is shown in Fig. 345. When a lateral branch is put in communication with the soil, it should be surrounded by charcoal, which is at the same time a good conductor of electricity and a preservative against rust.

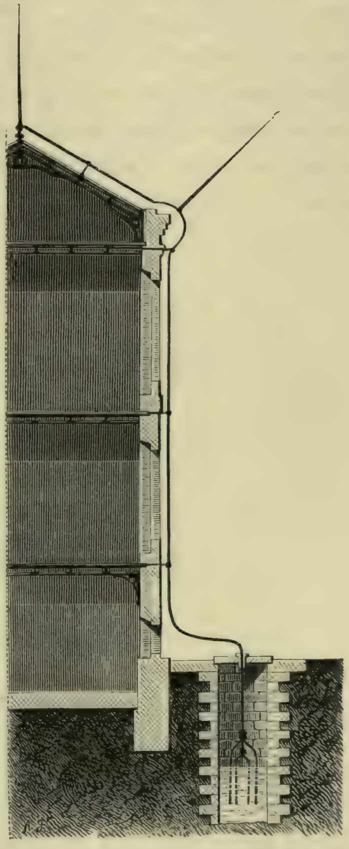


Fig. 345.—The fixing of lightning-conductors. Vertical and oblique rods.

Numerous facts prove the efficacy of lightning-conductors, but for this efficacy to be real, the apparatus must fulfil all the conditions above enumerated. The number also of the lightning-conductors and the height of the rods must be determined by the dimensions of the buildings they are designed to protect. Experience has shown that the greater the height of the rod above the ridge of the building, that is above its junction with the conductor, the wider is the range of its protective power. The radius of its range is about twice the height of the rod. These facts enables us to determine the number of lightning-conductors which must be set upon a house or other building. The rule, according to Arago, may be stated as follows :—"The smaller the height of the rods the more of them there should be. Their number will be sufficient, provided that no point on the top or on any terrace is at a greater horizontal distance from the nearest rod than double the height of that rod above its base."

Vertical lightning-conductors are sufficient when the building is not of great height, when it is, the sides must be specially protected, for there are instances of buildings struck by lightning at points far

below their summits. Rods placed obliquely or even horizontally will have the effect of discharging those parts of the clouds which in the time of a thunderstorm descend to within a short distance of the ground, and against which the vertical points of lightning-conductors have no neutralizing action; of course the oblique rods must have their conductors as well as the vertical. Besides this it is advisable to place all the lightning-conductors' rods of the same building in communication by metallic bars running along the ridges, but each should have notwithstanding, as far as possible, a separate conductor. Many conductors may without inconvenience be brought to terminate in the same well, but if several bars are united into one, it must have a section in proportion to the number of conductors it replaces.

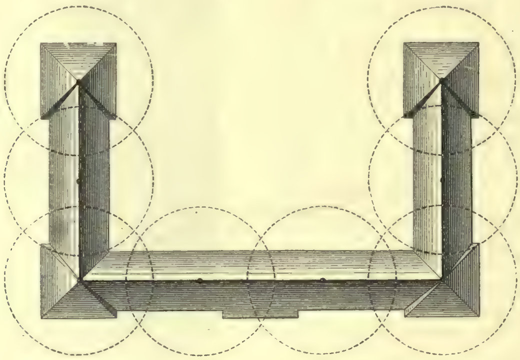


FIG. 346.—Limits of protection of a system of lightning-conductors fixed on a building.

Of late years lightning-conductors with multiple points have been much recommended as the best preservative against lateral discharges of lightning. Of all the buildings that should be preserved from lightning, the most important are the magazines of explosive or fulminating materials, such as gunpowder, gun-cap manufactories, powder magazines, &c. In this case, however, it is preferable to surround the place with towers of wood or masonry, on the top of which the rods are fixed. The reason of this precautionary arrangement is easy to understand. It is not sufficient to prevent the building from being struck by lightning, the electric flow which passes off by the rods and conductors must also be prevented from coming in contact with the masses of air that are near the magazines where dangerous materials are manufactured, or even stowed. In this air floats a fine dust of

inflammable particles, from which the current of electricity must be kept as far as possible.

Ships at sea, from their form and the height of their masts, are

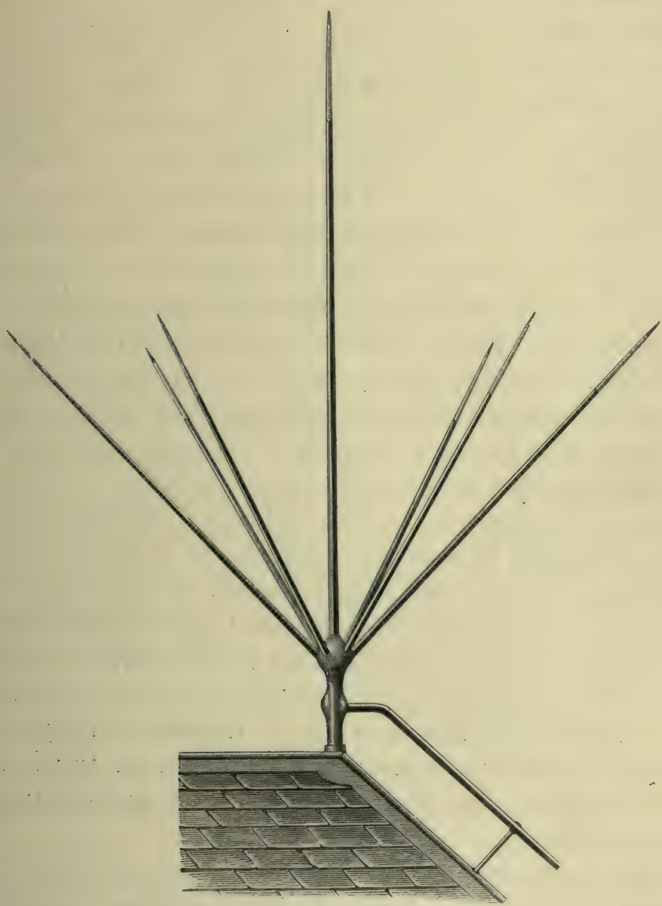


FIG. 347.—Lightning-conductor with multiple points.

much exposed to the strokes of lightning. It is therefore very important to provide them with one or more lightning-conductors, whose vertical rods are fixed to the summits of the masts. The conductors may be either rods or metallic ropes, which join the copper covering of the keel. The constant communication with the immense mass of the sea, renders the protection of this apparatus always effectual.

Harris has invented for the protection of ships a system of

lightning-conductors which has been adopted in the British navy, and which has the advantage over rods or ropes of metal of adapting itself to all the movements and all the varying positions of the masts. This system consists in placing sheets of copper round the mast and in communication with the sheathing of the ship. The result of this is, that in bad weather when the masts are broken by the violence of the wind, the lightning always finds a system of conductors sufficient for the discharge of the stroke and rendering it inoffensive. Arago states that the English frigate *Dryad* was often exposed, off the coast of Africa, to violent storms, called by sailors tornados (the ship was provided with Harris's new lightning-conductors). The electricity came down along these continuous pipes of copper in such quantity as to give rise to a sort of luminous atmosphere, and a noise like water boiling very fast. The ship was nevertheless preserved throughout.

Professor Clerk Maxwell, who has recently investigated this subject, has come to somewhat different conclusions. Taking the extreme case of a powder magazine, he states that, "It is quite sufficient to inclose the building with a network of a good conducting substance. For instance, if a copper wire, say No. 4, B.W.G. (0·238 inches diameter), were carried round the foundation of the house, up each of the corners and gables and along the ridges, this would probably be a sufficient protection for an ordinary building against any thunderstorm in this climate. The copper wire may be built into the wall to prevent theft, but should be connected to any outside metal, such as lead or zinc on the roof and to metal rain-water pipes. In the case of a powder-mill it might be advisable to make the network closer by carrying one or two additional wires over the roof and down the walls to the wire at the foundation.

"If there are water or gas-pipes which enter the building from without, these must be connected with the system of conducting-wires, but if there are no such metallic connections with distant points, it is not necessary to take any pains to facilitate the escape of the electricity into the earth. Still less is it advisable to erect a tall conductor with a sharp point in order to relieve the thunder-clouds of their charge."

It is hardly necessary to add that it is not advisable during a thunderstorm to stand on the roof of a house so protected, or to stand on the ground outside and lean against the wall.

CHAPTER III.

ELECTRIC TELEGRAPHY.

§ I.—Invention of Electric Telegraphy.

Telegraphy, or the art of communication at a distance, so as to transmit orders, news, or instructions in a detailed and precise manner, is quite a modern invention, a contemporaneous art, as we may say. We have shown in the chapter devoted to telegraphy, what are the elementary means of communication which all nations have used from time immemorial in order to correspond rapidly at great distances: bonfires, speaking-trumpets, the human voice transmitted from watchman to watchman, firing of cannon, maritime signals consisting of combinations of visible objects, all these methods depend on the rapid, almost instantaneous, propagation, of two physical agents, one, however, much slower than the other, namely, sound and light.

But it was not till the close of last century that any attempt was made to bring telegraphy to sufficient perfection to be used in the transmission of government despatches, and to insure the secrecy of these despatches, while giving them the same degree of precision as the language itself. Chappe's air telegraphs were adopted in 1793 by the National Convention in France, and soon after spread into civilized countries. But before even these were conceived, attempts had been made in an entirely different direction; a new science, electricity, had revealed the existence of an agent which is propagated with a velocity comparable with that of light, and the idea of making use of phenomena of this kind for rapid communication was spreading on all sides. Fifty years had scarcely passed before the electric telegraph had been invented and had dethroned the air telegraph.

In these days the metallic threads which serve to transmit human ideas with the velocity of lightning, in the interests of commerce, politics and science, as well as for private correspondence, circle the entire globe. They form a network of prodigious length, which not only covers continents but crosses oceans and seas, and unites all the nations of the world, from Europe to the Indies, China and Japan, Australia and New Zealand, and North and South America. From the American continent this marvellous chain will ultimately cross the whole extent of the Pacific to join Japan and China, and thus complete the circuit round the terrestrial spheroid. We will give further on the statistics of the universal electric telegraph; but pass now to sketch the history of this marvellous invention.

To give this history in all its details would require a volume. It must suffice us to indicate rapidly its principal phases, and to show how these phases are connected with the progress of science itself.

Before the invention of the voltaic pile, the projects for electrical communication, although sufficiently numerous, never had any serious practical application. In Le Sage's system (1774) the electricity of a machine was transmitted by isolated metallic wires to an electroscope whose movements marked the letters of the alphabet; there were in this case 26 wires according to the number of letters. Later, in 1798, Béthencourt substituted the discharges of a Leyden jar for those of an ordinary machine, and the system was applied between Aranjuez and Madrid over a distance not less than 27 miles. An analogous system was constructed in 1787 by the French physician Lomond. Reiser in 1794, Cavallo in 1795, Salva in 1796, and Ronald, lastly, in 1823, made use also of statical electricity for the transmission of signals, with a modification of the method of indication, as, for instance, the employment of sparks made to discharge upon a fulminating pane.

The discovery of the voltaic pile directed the attention of inventors to a more interesting method, and one much nearer to the true solution. Cox, the American, in 1800, Sœmmerring in 1811, and lastly Schweigger, the inventor of the multiplier, in 1828, had successively the idea of making use of the chemical properties of the voltaic current. The bubbles of oxygen and hydrogen arising from the decomposition of water gave by their disengagement at one station, various

signals agreed upon and produced at the other station, that is, at the opposite extremity of the conducting wires, by the successive interruption of the current.

A new advance in the science, namely, the discovery of the action of currents on magnetized needles (Œrsted, 1820), was the starting-point of new researches which led at last to the desired end. Even in the same year as this fundamental discovery Ampère defined this end and indicated in these terms the means of attaining it.

"We could," says this illustrious physicist and philosopher, "by means of as many conducting wires, and of magnetized needles, as there are letters, establish, by the aid of a battery placed at a distance from the needles, and which could be made to communicate alternately by its two extremities with those of each conductor, a sort of *telegraph* which might write all the details we wished to transmit, over the intervening space, to the person charged to observe the letters placed over the needles. By fixing above the battery a key-board whose keys denoted the same letters, and by establishing the communication by their depression, this means of correspondence could be easily carried out, and would require no more time than that necessary for touching the key at one place, and reading each letter at the other."

Ampère's idea was not realized in the shape in which he formulated it. The number of galvanometers, each of which was to correspond to a single letter of the alphabet and to each further sign to be transmitted would have been too great, but we shall see in time, when we describe the needle electro-magnetic telegraph, that it is the same principle that dictates its construction. It is to Wheatstone that we owe the improvements and simplifications which have given to Ampère's conception all its practical importance.

But before it arrived at a complete realization, this conception was applied in various ways, by Schilling in 1833, by Gauss and Weber in 1835, by Richtie and Alexander in 1837. The first of these applied his system at St. Petersburg, but on a small scale. "Five platinum wires were inclosed in a cable of silk each joined by one of its ends to a multiplier, and by the other to a key-board like that of a piano. On sending the current of a battery through one of these wires, by putting down the key corresponding to it, the needle deviated to one side or the other according to the direction of the current. This formed with the five needles ten different signs. Messrs. Richtie and

Alexander constructed at Edinburgh in 1837 an apparatus on the same system. It had thirty needles corresponding to as many wires stretched between the two stations and made a corresponding number of signs. Gauss and Weber employed also this kind of apparatus for communication between the physical laboratory and the observatory of Göttingen." (Daguin.)

The time had now arrived (1837 and 1838) when the electric telegraph was about to pass from the period of attempts and experiments to that of true practical realization, and the names of Wheatstone, Cooke, Steinheil, Morse, Masson, and Bréguet recall the important labours, discoveries, and improvements which characterise the different systems successively adopted. We will here then leave our historical notices to enter on the description of the systems, but we must draw attention, by an example, to the manner in which the applications of science are bound up with purely scientific progress. Without the discovery of the new forms of battery, without the substitution of constant currents for the currents of the first kind of batteries whose intensity so rapidly decreased, it is probable that the marvellous art of electric telegraphy would be yet in its infancy. It would be still a curious application of physics, and not an invention in use and of universal value.

§ II.—THE ELECTRIC TELEGRAPH.—GENERAL THEORY.

A piece of soft iron in the form of a horse-shoe, round which is twisted a helix or spiral made of an insulated metal wire, constitutes an *electro-magnet*, that is to say, a temporary magnet, whose magnetic power continues during the passage of the electric current through the wire and ceases as soon as the current is interrupted.

This temporary magnetisation is instantaneous, and it ceases with the same rapidity as it commences. It follows from this that if by any means whatever we can make a current of electricity pass through the coil of an electro-magnet, and then cut it off, in a rapid series of operations composed of this double elementary operation the attraction of the pole of the magnet for its armature will be reproduced and suspended the same number of times. This property is made use of to obtain a series of alternating movements of the armature; it is

sufficient for this purpose to arm the latter with a spring which keeps it at a short distance from the poles, without preventing it coming in contact with them every time the current passes. On this principle is based the construction of the machines known as electro-magnetic engines, because electricity is the source of the motion they produce. This motion, which it has been attempted to utilize for purely mechanical purposes, as we shall see in a future chapter, serves for the production of signals which can be transmitted with very great rapidity to considerable distances, owing to the enormous velocity with which electricity is propagated in a conducting wire. Such, reduced to its simplest form, is the method of producing motion most generally adopted in the different systems of electric telegraphy.

Nevertheless, in certain of these systems, the electric current acts either directly on the needles of a galvanometer or indirectly by its chemical or electrolytic properties. But whatever in other respects

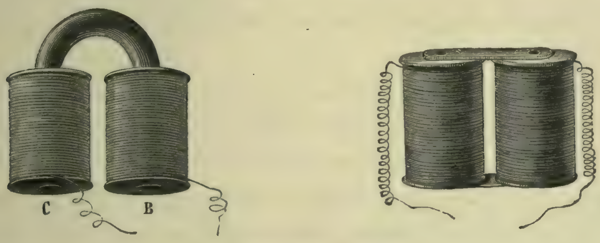


Fig. 348.—Electro-magnets.

may be the mode of action of the electricity, an electric telegraph is always necessarily composed of the four following parts :—

First, an apparatus for producing the current, that is to say, an *electro-motor*. This is sometimes a galvanic battery, sometimes an induction machine, either magneto-electric or electro-magnetic.

Secondly, an apparatus of transmission, forming a circuit, or electro-dynamic *conductor*. This is the wire or wires of the line joining the sending and receiving stations of the signals.

In the third place an apparatus for producing the signals, called a *manipulator*, which is handled by the person sending off the message.

In the last place, there is a receiving apparatus, by which the signals sent are reproduced at the receiving station; this is called the *indicator* or receiving instrument.

We shall see presently that in an electric telegraph there are other

secondary apparatus, such as the alarums or warning apparatus, relays, and lightning conductors. They will be described in their place.

Such are the principles of electric telegraphy, as it has been practised up to the present time. The number of systems which have been and still are in use in the universal network is very large. We can only propose to describe those in most general use; and among these the most original, that is, those which are distinguished by some characteristic idea, by a special mechanism, or a particular method of signalling. From this latter point of view we may class the electric telegraphs in use under five groups.

1st. The needle telegraphs. These have the indicators composed of magnetised needles under the immediate action of the current which circulates in a coil, which causes deflections to the right or left, which are the elements of the signal.

2nd. The dial telegraphs, in which the indicator consists of a dial with an indicating needle whose motion is regulated by an electro-magnet, under the action of a current alternately sent through the line and interrupted.

3rd. The writing telegraphs where the message sent is traced by the indicator on a band of paper which unrols itself continuously; the signs which are stamped or marked in ink are produced by a style, whose motion is due to the passage or interruption of the current.

4th. The printing telegraphs, where the message itself is printed in typographic characters, no translation being any longer necessary.

5th. Autographic telegraphs which reproduce not only the text but the facsimile even of the writing of the message, so that signatures and drawings may be sent and reproduced in the original form. These apparatus have received for this reason the name of pantelegraphs (from the Greek πᾶν all).

We pass now to the details of the mechanism of the principal systems of telegraphy just enumerated.

§ III.—Needle Telegraphs.

We commence with the needle telegraphs, which, as we have seen above, are those which first received the sanction of serious and practical experience.

It is to Wheatstone that their invention is due.

At first this illustrious electrician employed five galvanometers, which required, including the return line, six wires. The five wires were disposed in this way. They were ranged in front of and along the central line of a lozenge-shaped frame, and the corresponding galvanometers were placed behind the frame opposite the ends of each wire. When a current was made, by the manipulator, to pass through two of the five galvanometers in an opposite direction, the two needles deviated at the same time, placing themselves diagonally and pointing to one of the letters inscribed on the frame. For example, the needles

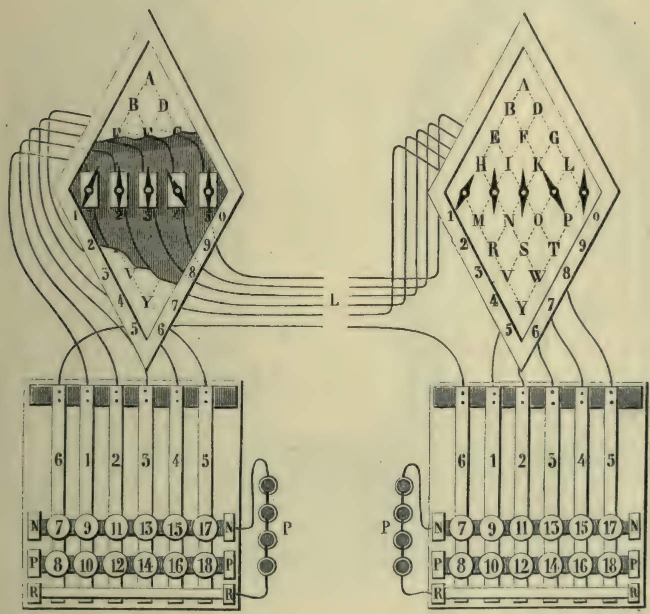


FIG 349.—Wheatstone's five-needle telegraph.

1 and 4 (Fig. 349) have their upper ends directed towards the top of the frame and indicate the letter B; if the current passed through the same galvanometers, but in opposite directions, the lower ends of the needles would be directed towards the base of the frame and mark the letter V. When a needle moves alone it indicates one of the ten figures written on the lower edge of the frame. Two similar dials united by five wires give the same indications at the same time when the sender of the message works the manipulator. By pressing

on two of the buttons marked with the figures 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, and 18, placed in two different horizontal rows, the current passes through the two corresponding galvanometers after having traversed the line wires and put in action the same needles of the receiving dial.

We will not describe the mechanism of the manipulator of this system, though it was successfully worked on the London and Birmingham Railway, until replaced by a simpler system ; in fact, Wheatstone in

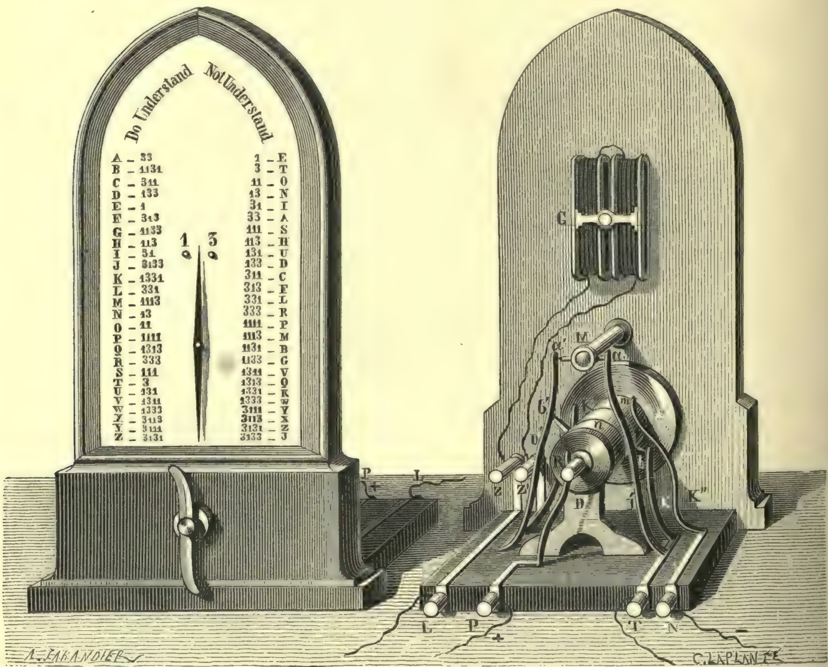


FIG. 350.—Cooke and Wheatstone's single needle telegraph manipulator and indicator.

conjunction with Cooke soon modified it, by reducing the number of galvanometers to two or even one. Hence arose the single needle, and two needle telegraphs which have been adopted on English telegraphic lines, and which we will now describe. The mechanism is as we shall see, of great simplicity.

Fig. 350 represents, on the left, the front face of the apparatus, which is the same at the receiving and sending stations.

In the centre, we see the outer needle of the galvanometer whose

deflections to the right or left are marked by the figures 3 and 1, and are limited on each side by an ivory button. At the bottom is the handle of the manipulator, which the sender turns to the left or to the right according to the direction of the deflection he wishes to produce. By combining the order and number of the deflections of the needle to the right or the left 1, 2, 3 or 4 movements are sufficient to represent the letters of the alphabet, the 10 digits, and signs in common use. The following are the signs agreed upon in England:—

A	33	H	113	O	11	V	1311
B	1131	I	31	P	1111	W	1333
C	311	J	3133	Q	1313	X	3113
D	133	K	1331	R	333	Y	3111
E	1	L	331	S	111	Z	3131
F	313	M	1113	T	3		
G	1133	N	13	U	131		

The figures are indicated by the number and order of the deflections to right or left of the lower point of the needle. The clerks

BELGIAN. ENGLISH.

FIG. 351.—Belgian and English vocabularies of the single needle telegraph.

pass from letters to figures and from figures to letters by a preconcerted signal. We need scarcely say that these combinations of signs are altogether arbitrary—thus the signals adopted in Belgium for this system of telegraphy were different to those just described, but the mechanism is not changed on that account.

We will now describe the manipulator of Wheatstone's single needle telegraph. As appears on the right of Fig. 350, which shows the back of the apparatus, the galvanometer G is placed in the centre of the vertical line as represented on the front face in the same figure. The indicating needle is mounted on the same axis as the magnetized needle of the galvanometer. They are also both magnetized, forming a compensating or astatic system as in Nobili's galvanometer (see *Forces of Nature*, book vi). What constitutes in reality the manipulator or commutator is situated below the galvanometer. It consists of a boxwood cylinder supported on two metallic bearings on the axis of the outer handle, and movable like it to right or left. On the outside this cylinder is covered by two metallic bands which are insulated from each other. The bearing D is in constant contact with the spring R, and also with the band *n*. Two metallic points *b* and *b′* rise from each of the bands and, according to their position, come one against the spring K, the other against spring U. The band *m* is in permanent contact with the spring K″. At M is seen a metallic rod armed laterally with two points which touch in *a* and *a′*, according to the position of the needle, either the spring U′, or the spring U. Lastly the galvanometer wires are joined to the two pieces Z and Z′ which are themselves united, the first with the end L of the line wire, the second with the springs U′ K′ and the wire of the positive pole of the battery; on the other hand, the springs K and U are joined to the earth-wire T, and K″ to the negative pole N of the battery.

This being given, imagine the handle of the manipulator vertical. In this case, the points *b* and *b′* are themselves vertical, and the metallic bands of the cylinder remain insulated; the current from the battery cannot pass from one to the other, nor in consequence enter the galvanometer wires.

Suppose the handle turned to the right—this is the case represented in Fig. 350. The two points *b* and *b′* press against the springs K and U′, taking the latter out of contact with the piece M. The current will then follow the path marked by the series of letters corresponding to the different pieces of the manipulator in the following order—P R D *n* *b′* Z′ G Z L; the current thus coming from the line wire after having deflected the upper point of the galvanometer needle in the sender to the right, pursues its course, enters the receiving apparatus and deflects the needle of its galvanometer in

the same direction, and then loses itself in the earth. As we shall see further on, the earth plays the part of the return wire, so that the negative pole of the battery of the sending apparatus completes the circuit by the intermediate pieces T K *b* *m* K″ N.

When, on the contrary, the handle is turned to the left, the direction of the current is reversed, on account of the position of the points *b* and *b′*, of which the first presses against the spring K′ and the second against the spring U, which is separated at the same time from

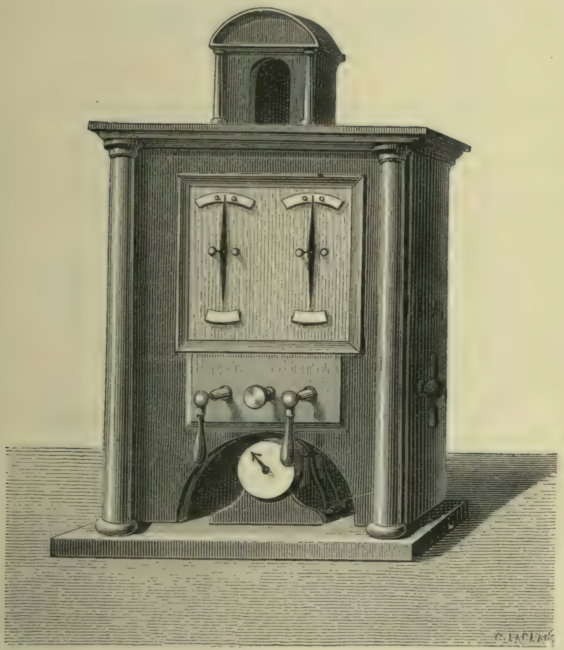


FIG. 352.—Two needle telegraph.

the piece M. The path followed by the current is then indicated by the series of letters N K″ *m* *b* K Z′ G Z L, the line, and then T U *b′* *n* R P. The current circulating in the opposite direction, deflects the needle of the sender to the left at the same time as that of the receiver.

We see then that the galvanic current, in this system, traverses at the same time, and in the same direction, the galvanometers of the two extreme telegraphic stations. It is interrupted simultaneously

in the two. The signals sent are thus reproduced at the same instant.

The *two needle telegraph* of the same inventors is based on the same principle as the preceding. The two apparatus of the sending and receiving stations are each composed of a double galvanometer and a double manipulator, independent of each other. The clerk who works them, takes, in his two hands, the two handles which move the manipulators to the right and left, he then turns them in one direction or the other, separately or simultaneously, so as to produce the signals which constitute the alphabet and the figures of which Fig. 353 is the table.

Needle to the left.		The two needles together.			Needle to the right.	
+	\	R or 8	\	\	\	H or 4
A	\\	S	\\	\\	\\	I
B	\\\	T	\\\	\\\	\\\	K
C or 1	\/	U or 9	\/	\/	\/	L or 5
D or 2	✓	V or 0	✓	✓	✓	M or 6
E or 3	/	W	/	/	/	N or 7
F	//	X	//	//	//	O
G	///	Y	///	///	///	P
		Z	/	\		
		Q	\	/		

FIG. 353.—Vocabulary of the two needle telegraph.

At the top of the apparatus (Fig. 352) is the alarum which announces the sending off of a message. On the side are two metallic bands which put the alarum in communication with the current in the line. The receiving clerk, as soon as warned, replies by a concerted signal that he is ready to receive—he then turns the handle seen at the side of the apparatus, so as to stop the communication with the alarum, and interrupt the ringing during the time the message is being received.

The dial placed below the handles of the manipulators is provided with a needle, which, according to its position on the dial, cuts off such and such stations on the line from the action of the current, or divides the line into two independent parts. This is called the

disconnecting apparatus. By the aid of the commutator, telegraphic communication may be kept with the stations interested, and the service continued independently between all the others.

In the two needle, as in the single needle, telegraph the deflections are limited by two little ivory pins, which have the further advantage of enabling the ear to catch the number of beats by the little blows of the needle upon the ivory. Other inventors have constructed different systems of needle telegraphs which have worked with

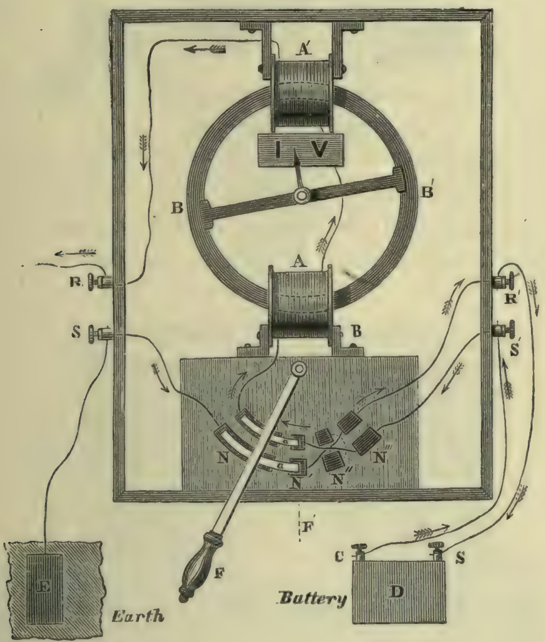


FIG. 354.—Bain's I and V telegraph, 1843.

success. We may refer to a few of them, simply noting the principle of their construction.

We mention first the two needle telegraph of M. Glœsener, which is nothing more than a modification of Wheatstone's. This modification consists principally in the addition of two electro-magnets to the multiplier of the receiving instrument, each of which acts upon a different pole of the three magnetized needles composing the galvanometer. The magnetizing coil of these electro-magnets is the continuation

of the multiplier. According to M. Glœsener, this addition doubles the power of Wheatstone's apparatus.

Bain's single needle telegraph depends upon a different principle to those just described. The electro-magnetic agent is an electro-magnet whose bobbins react on two permanent magnets in the form of semicircles, movable about an axis which carries the indicating

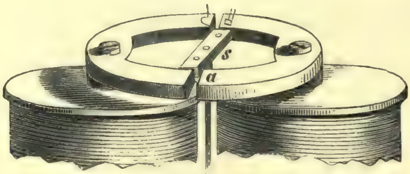


FIG. 355.—Henley and Foster's magneto telegraph, 1848, Indicator movement.

needle. The simultaneous attractions and repulsions in one direction or the other produced in the poles of the electro-magnet and the permanent magnets by the passage of the galvanic current deflect the needle to the left or bring it back to its vertical position. The

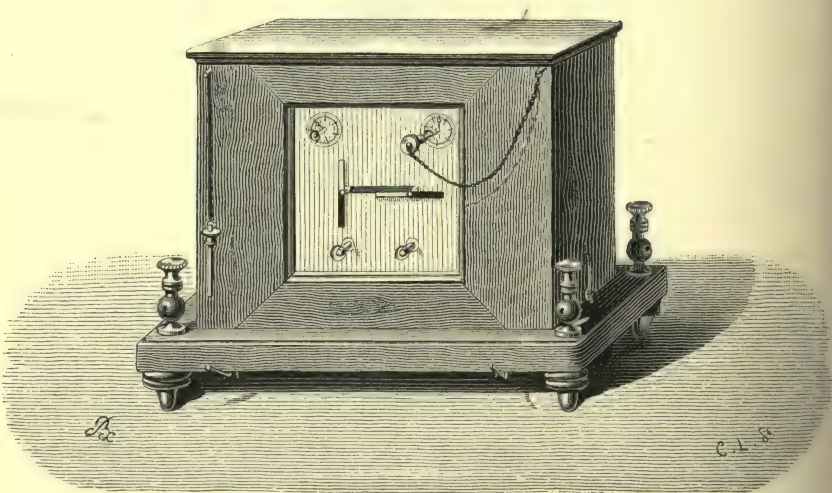


FIG. 356.—Indicator of needle telegraph, Foy and Bréguet's system.

manipulator is a simple commutator for reversing the poles, worked by a handle, the latter being brought back to the vertical by springs. Bain's telegraph used to work between Edinburgh and Glasgow from 1846 onwards.

Henley's needle telegraph has for its moving agent a magneto-electric machine. An electro-magnet is made to turn in front of the poles of a strong permanent magnet in the form of a horse-shoe: by means of a little ivory knob which is pressed by the finger, an induced current may be set up, which circulates in the line and the indicator, and as soon as the finger is raised, a second current passes in the opposite direction. The indicator is itself an electro-magnet provided with two pieces of soft iron at its two poles, and between these two pieces, which are in the form of a horse-shoe, is placed a magnetized

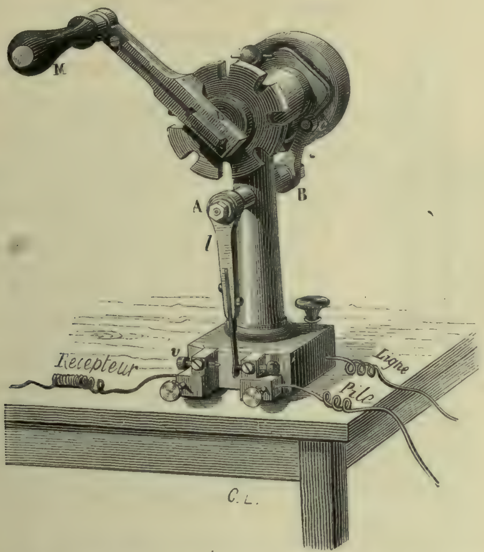


FIG. 357.—Manipulator of Foy and Bréguet's needle telegraph.

needle whose deflections are repeated by an indicating needle mounted parallel to it on the same axis. The signs in Henley's telegraph are similar to those of Morse's as described further on.

Foy and Bréguet have invented a needle telegraph, reproducing the signals of Chappe's air telegraph. This system has been worked since 1845 between Paris and Rouen (145 kilometres), and has given, as it appears, excellent results. Like Wheatstone's two needle telegraph it required two lines of wire—but the inventors have constructed apparatus with a single needle only which require but one line and still give from 100 to 120 signals a minute.

Figure 356 represents the indicator, which consists of two symmetrical and independent apparatus, each corresponding to one of the indicating needles. These needles, half black and half white, can take eight positions about their centres, two horizontal, two vertical, and four at angles of 45° with each of the others, which gives 64 disposable signals. The mechanism of the indicator has much analogy with that of Bréguet's dial telegraph which we shall presently describe in detail. By turning the handle M of the manipulator, which is in duplicate, and giving to it one of the eight positions corresponding to the eight notches of a fixed wheel, another wheel is made to move which is mounted on the axis of the handle, on the plane of which is traced a hollow sinuous furrow. The spring B *c* then takes either the position seen in the figure, and then the piece *l* touches the metallic piece *v*, or a position nearer the centre, *l* in this case goes over and touches the piece *v′* on the left. The two pieces *v* and *v′* are insulated by a piece of ivory from the metallic part of the manipulator, in which end respectively the wires of the battery, the line, and the indicator. There is thus sometimes a passage, sometimes an interruption of the current, which produces in the indicator the corresponding movements of the indicating needle.

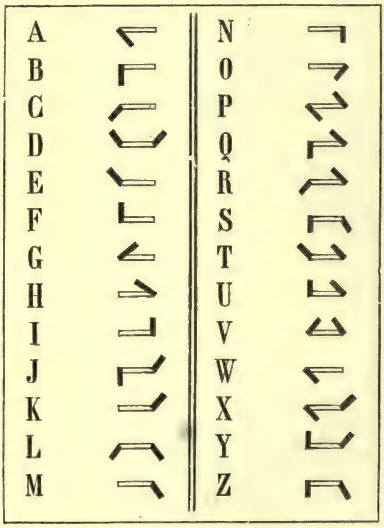


FIG. 358.—Vocabulary of Foy and Bréguet's needle telegraph.

The above is the vocabulary adopted for the French needle telegraph. The horizontal mark is common to all the signals and requires no operation. Seven letters, A, B, C, E, F, G, W, only require the action of the left hand manipulator, six letters, H, I, K, M, N, O, only that of the right hand manipulator. The thirteen other signs require the simultaneous movement of the two manipulators and the two apparatus. This system has been for a long time employed by the authorities of the French telegraphic lines.

§ IV.—Dial Telegraphs.

The dial telegraph is chiefly employed for the railway service and for private telegraph wires between offices and manufactories. The chief reason for this preference consists in the facility with which the apparatus is worked, as it allows any telegraphic operator after a very short apprenticeship to send a message and to read the signals received.

It is to Wheatstone that we owe the invention of the first telegraph of this kind. The first attempts with it were made in France

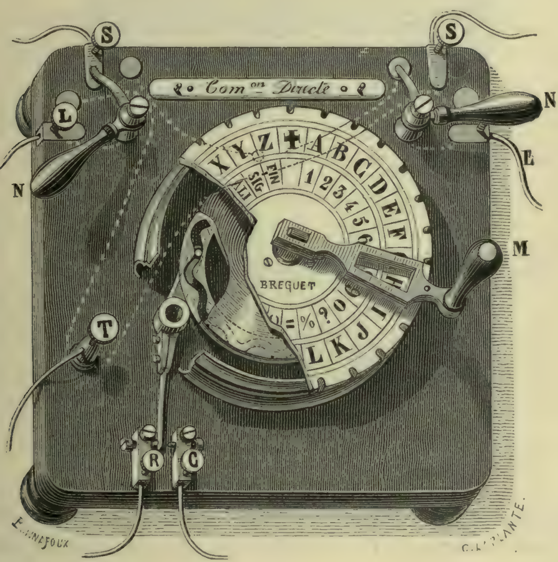


Fig. 359.—Manipulator of Bréguet's dial telegraph, new form.

in June 1844, on the railway from Paris to Versailles. Since then a great number of analogous systems have been tried and adopted on the different telegraphic lines in different countries. We will mention a few of the most remarkable, indicating the differences in their principle or mechanism, confining ourselves just now to the description of the system, which of all the dial telegraphs is in commonest use on the railways of France—that of M. Bréguet, derived from Wheatstone's.

Figures 359 and 360 represent the manipulator.

It is a brass dial supported by three metal columns on a horizontal wooden base. Two concentric zones of the surface, divided each into twenty-six sectors are marked—one with twenty-five letters of the alphabet (French) and a cross, and the other with the successive numbers from 1 to 10, with a series of signs or special signals. These signs were placed in the original instrument by the numbers 10—25 (Fig. 360). On an axis which passes through the centre of the dial a handle is attached which can be moved in the direction of the hands of a watch and stop against any of the letters or figures; for this

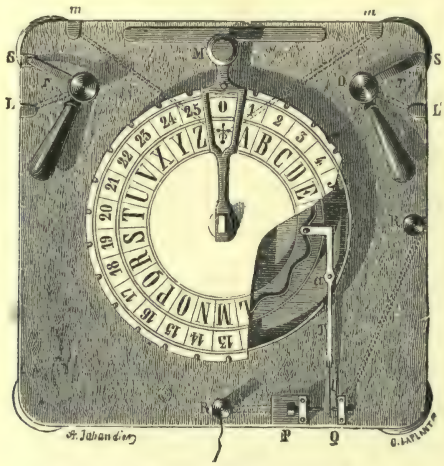


FIG. 360.—Bréguet's manipulator, old form.

purpose the handle carries a tooth which catches in one of the notches cut in the circumference of the dial at the middle of each of the twenty-six sectors.

The movement of the handle involves that of its axis, and of a movable wheel in which is sunk a sinuous groove, seen where part of the dial is supposed to be removed in the figure. The sinuosities of this furrow are as numerous as the sectors, that is, there are thirteen concave and thirteen convex arcs, all corresponding to the letters or the numbers. A bent lever, T, jointed at *a* (Fig. 360), carries a little rod upon which runs a little roller of tempered steel. The motion of the wheel is thus communicated to the roller in the concave part of the groove, so that the end of the lever is sometimes carried nearer and

sometimes further from the centre, performing in this way as many oscillations as the handle passes over successive divisions on the dial.

We now see how the motion given to the handle of the manipulator produces a series of completions and interruptions of the current in the line wire. We must next describe the different pieces of the manipulator and the communications they make between the batteries, the line wires, and the apparatus themselves.

The wire which comes from the positive pole of the battery reaches the end R, which is connected by a metal band to the screw P. Opposite the point of this screw is that of another, Q, which is connected in the same way with the end R′ to which is attached the wire of the indicator. Between the points of these screws the oscillation of the branch of the lever T takes place, which touches first one and then the other. Suppose the manipulator at rest, or the handle at the cross, which is the position indicated in Fig. 360. In this case, the current does not pass, for the circuit is not closed, and the same is the case whenever the lever has the same position, that is to say each time that the handle passes over an even division, as B, D, F, or the figures 2, 4, 6. If, on the contrary, the needle in moving passes over, to an odd division, or stops there, the current enters by the lever T to the movable wheel of the manipulator. It remains to shew how it is sent through one or other of the line wires, to the right or the left of the station. It is in L and L′ that these wires end. The two metal tongues L and L′ are in permanent connection with two spring commutators $r\,r'$, which may be turned by means of a handle, and whose springs connect them at will either with the tongues Sm S′m' or with ends of the metal band CD.

If it is required to communicate with the telegraphic station to the left, the spring of the commutator r must be placed upon m; to correspond with the right, the spring r' must be placed on m'. The two pieces m and m' are in metallic connection with the movable wheel of the manipulator. Then if a current from the battery arrives in this wheel it passes through m, the spring r, the attachment L and the wire to the left as stated. The current sent along the line arrives at the indicator of the receiving station, then through the earth wire of that station, and returns by the earth itself to the negative pole of the sending station. The same process takes place in the line to the right

if it is the right hand commutator whose spring has been placed on the tongue m'.

To sum up, if a motion of rotation is given to the handle of the manipulator, so as to make it perform a complete revolution, there will have been thirteen passages of the current through the line wire, and thirteen alternate interruptions of it. Suppose we wish to send the word "Paris," that is to employ the five letters P, A, R, I, S. After a warning—to the description of which we will return—the sender turns the handle from the cross to the letter P and leaves it for an instant in the corresponding notch, and then continues the turning round to the

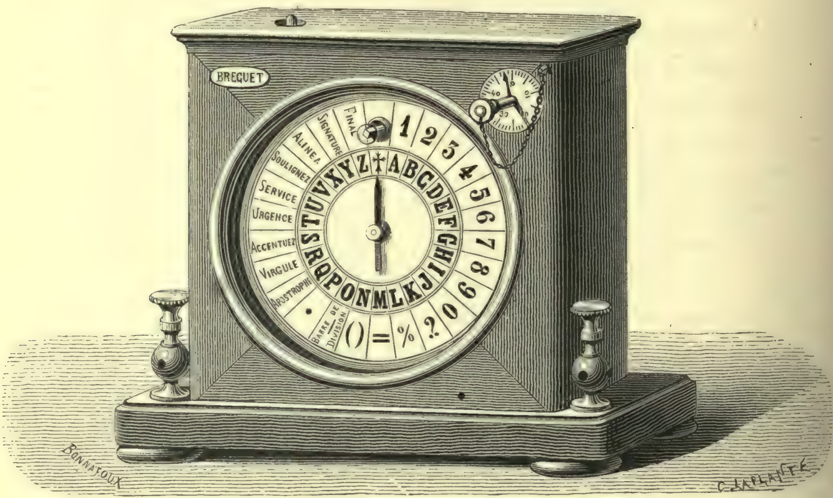


FIG. 361.—Indicator of Bréguet's dial telegraph, external view.

cross. He stops at the letter A, and then passes to the letters R, I, S, in the same manner.

Each time, that is for each turn, the number of sendings and interruptions of the current is twenty-six, but there is a moment of stoppage, corresponding to the moment when the handle stops at the letter to be sent. These sendings and interruptions and stoppages are reproduced in the same order at the receiving station, and it remains to shew how they are indicated in the receiving apparatus of that station, by making a needle move over the dial of that apparatus, and reproduce identically the motions of the handle.

We will describe the indicator first.

Fig. 361 represents the outside appearance. It is a box provided with a dial, having the same divisions as the dial of the manipulator. In the interior some clockwork is fixed, whose escapement wheel and the needle of the dial are on the same axis, so that each time a tooth of that wheel passes, the needle moves over one division. The current sent through the line by the manipulator of the sending station arrives at one of the binding screws, seen at the base of the indicator, passes along the wire of the bobbins of an electro-magnet

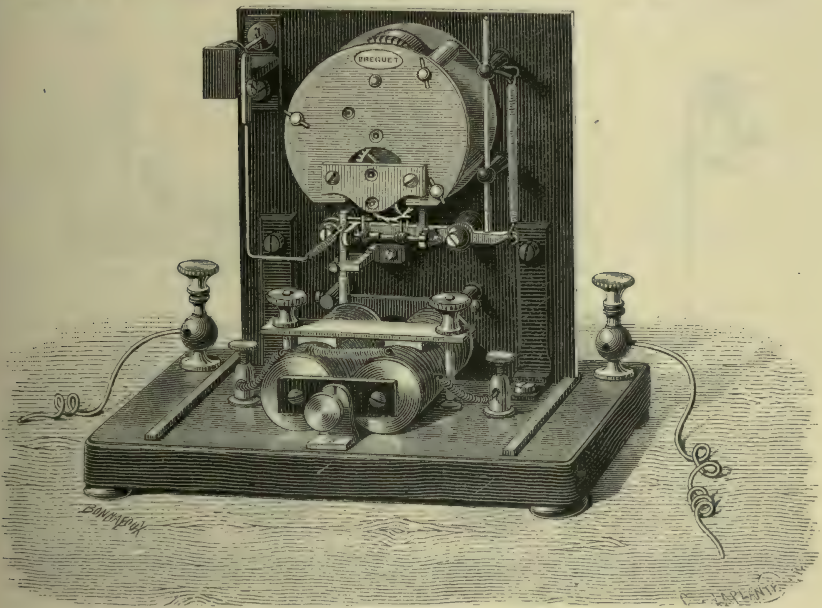


FIG. 362.—Bréguet's indicator, view of the mechanism.

placed in the inside and base of the indicator, acts on a peculiar mechanism we will presently describe, and passes to the earth through the other binding screw. We have to show further what is the method of the current's and the electro-magnet's action on the escapement wheel, in order to complete the explanation of the way in which the signals, letters, or figures sent, are reproduced on the dial by means of the needles, this is rendered easy by the study of Figs. 362 and 363, which represent the special mechanism of the receiving

apparatus. At the base of the apparatus, resting on the stand, is seen the electro-magnet, through the bobbins of which the current sent through the line by the receiving station circulates. In front of its poles is an armature of soft iron M, Fig. 363, carried by two screws, between which it can oscillate about its horizontal bearings at the top. When the current passes, it is attracted by the poles, then excited, of the electro-magnet, and rests against them. When the current is interrupted it leaves the poles by an opposite motion towards the front of the indicator where the dial is fixed. This reciprocating motion of the armature M is communicated by a special mechanism to the indicating needle. It carries for this purpose a vertical rod L, which

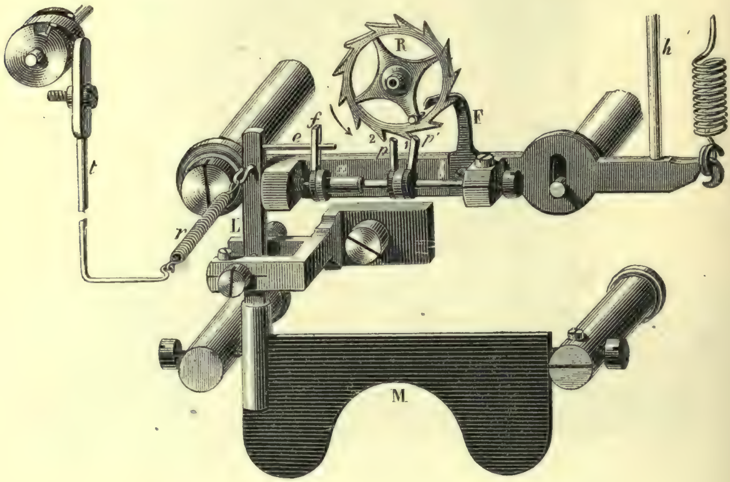


FIG. 363.—Details of the mechanism in Bréguet's indicator.

oscillates like the armature, but in an opposite direction. This rod, limited in its motions by two screws, carries at its end a pin *e* which works in a fork *f*, so that the latter oscillates sometimes forward, sometimes backward, and communicates its own oscillations to a shaft *ab*, and so to the pallet *pp'*, whose special purpose is to let go or stop the teeth of the escapement-wheel R.

Suppose the indicator at rest, the indicating needle being on the cross, the pallet *p'* is stopped against the tooth 1 of the wheel, and the wheel is immovable. When an emission of the current takes place—that is to say, when the needle of the manipulator advances from the

cross to the letter A—the current passes along the line, enters the indicator and the electro-magnet, which draws into contact the armature M. The motion of the latter causes the rotation in the opposite direction of the shaft *ab* of the pallet *p*, which lets the tooth 1 escape, and the tooth 2 comes to a stop against the pallet *p* when the wheel has been made to move by the escapement-motion having turned it. The indicating needle has then advanced through one division and stops at A.

When the current ceases the armature returns to its first position under the action of the spring *r*, the pallet *p* lets tooth 2 escape, the wheel moves again, and the pallet *p'* stops in its turn at the tooth 2 ; the needle has turned through another division; a very simple arrangement allows the needle to be returned to the cross without sending a current (which is sometimes necessary). By means of the rod *h*, seen on the right, the shaft which carries the pallets, and the pallets themselves, can be lowered; these no longer catch against the teeth of the escapement-wheel, and the wheel moves until a roller F encounters a stoppage suitably placed, which corresponds to the position at which the needle is at the cross.

The little dial seen on the left hand at the top of the indicator, serves to regulate the spring *r*. If this spring were not suitably fixed, the magnitude of the oscillations of the armature might be too great or too little; in the first case the pallets would be liable to go out of the plane of the escapement-wheel, and the wheel would move without interruption; in the second case the pallets could not disengage the teeth, and there would be no escape: the indicator would not work. It remains to show how the apparatus at a station are arranged, and we will take for example an intermediate station which can correspond along the line with two neighbouring stations, one situated at the right, the other to the left of the first.

Take the station at Sèvres, on the telegraph line between Paris and Versailles. Fig. 364 represents the manipulating and receiving apparatus. The manipulator is fixed on a table, and on either side are seen the galvanometers which give notice of the transmission of currents over each wire of the line. Above on the same horizontal table are placed the indicator, and on each side the alarum which gives notice of the sending off a message, whether to the side of Paris or to that of Versailles. We shall see in a minute how these alarums act.

Let us examine the different cases that may present themselves, and see how the post office clerk will act under these circumstances. The apparatus being at rest, the tongues of the commutators are upon S and S′, (see Fig. 360), to which are joined the wires of the two alarums. If the clerk at Paris wishes to send a message to Sèvres he makes the handle of the manipulator pass over an entire circle; the current thus sent into the line enters the station at Sèvres by the right hand wire, deflects the needle of the galvanometer, and acts on the mechanism of the right alarum. Warned by the noise, the clerk puts the commutator

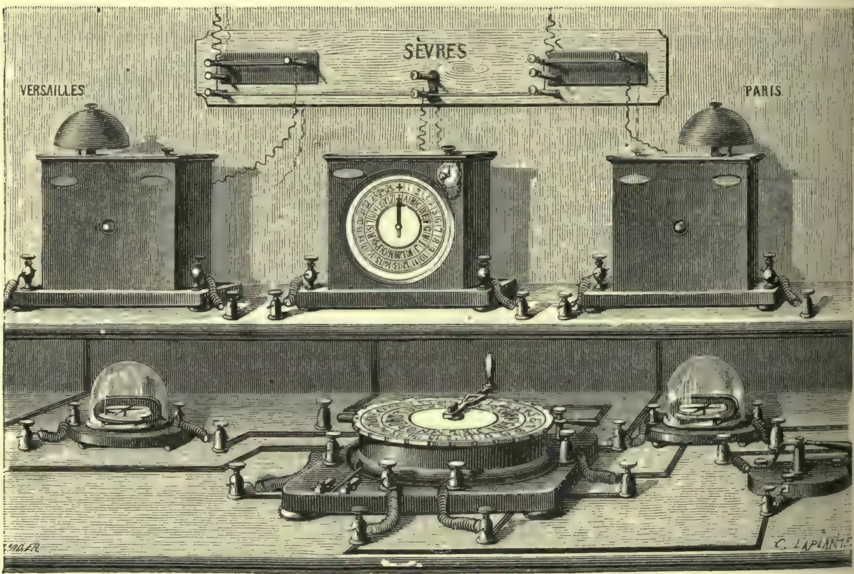


FIG. 364.—A dial telegraph station.

to the right on m', and then, making the handle of his manipulator describe a whole circle, a similar motion of the indicating needle is caused at Paris, and in this way he announces that he is ready to receive the message. The message sent and understood, the clerk at Sèvres sends in his turn the two letters C O (*compris*).

To send numbers, the letter C twice repeated is sent first.

What we have just said will enable the reader to understand the plan which the clerk at Sèvres must follow if he wishes to send a message to Paris. The explanation is entirely the same, except the

order; the whole takes place on the other side if the correspondence is to be between Sèvres and Versailles.

Suppose now the stations at Paris and Versailles wish to correspond directly. The sending station sends to Sèvres the name of the station to which the message is to go, and allows the necessary number of minutes to elapse. The clerk at Sèvres replies C O (*compris*), and then he puts the commutators on the bar for direct communication, C D. All correspondence is stopped for this station during the whole time the message is passing, a time which the motion of the galvanometers suffice to indicate. The message passed, the clerk replaces the commutators on the contacts of the alarums.

§ V.—DIAL TELEGRAPHS (*continued*).

There are several systems of dial or letter-showing telegraphs, but practically they are reduced to two, namely the Siemens and Halske system and the Wheatstone system. These two systems are based upon the successive step by step development of the telegraph over a series of years. Two of the more important of the early step by step letter-showing telegraphs, those of Wheatstone in 1840 and Nott and Gamble in 1846, are figured below. In Wheatstone's, the successive letters forming the word appeared at the distant station at an opening in the dial plate; the communicator dial of the instrument is furnished with an alphabet, and the rotation of this dial bringing the required letter to the zero, sends into the circuit the necessary succession of "make and break" currents to cause a similar step by step rotation of the distant indicating dial, by which means the required letter is brought to view.

In Nott and Gamble's dial telegraph, Fig. 366, the respective letters or numerals were indicated by the step by step motion of a revolving pointer, the necessary letter being indicated and controlled by successive "make and break" contacts with a battery by means of a finger key and mercury cell *h*. Two electro-magnets *a* and *d*, acting upon soft iron armatures in connection with a "Clawker" and driver motion, rotated the toothed wheel *c* and external pointer. The electro-magnet *b* controlled the alarum or call signal.

The Siemens and Halske letter-showing telegraph, Fig. 367, is chiefly

in use upon the continental lines of railway. The motor of the apparatus consists of a battery of permanent magnets, about the poles of which turns a cylinder of soft iron covered in the direction of its axis with an isolated iron wire, forming a magnetizing coil. The rotation of this cylinder on its axis develops induced currents alternately in opposite directions. These currents thrown into the line one after the other, act upon the electro-magnet of the indicator and make its armature oscillate, which in turn acts on the escapement wheel carrying the indicating needle. Fig. 367 represents the exterior of the complete instrument which is, as we see, very simple. A is a drum or cylindrical box con-

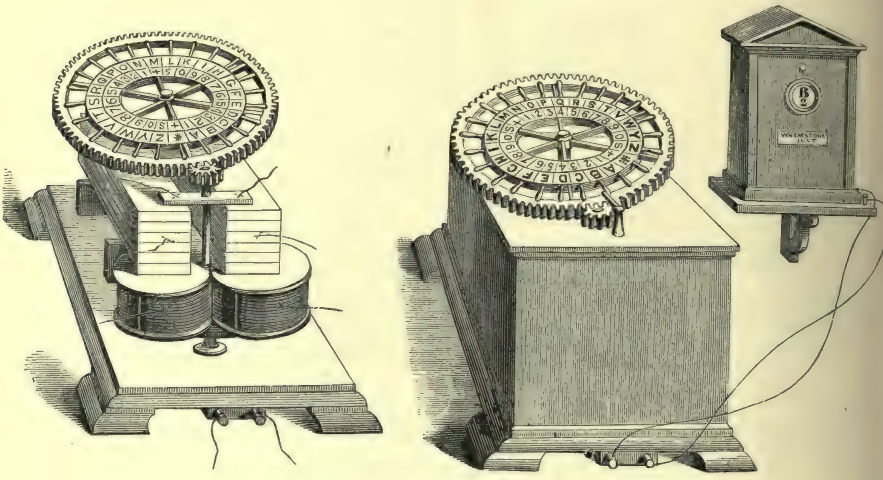


FIG. 365.—Wheatstone's letter-showing dial telegraph, 1840.

taining the transmitter or manipulator, B is the indicator, M O is the handle which the sender turns and stops successively at the letters of a dial according to the tenor of the message. The needle of the dial of the indicator B follows all the movements of the handle of the manipulator.

We will briefly indicate what are the principal arrangements of the mechanism of each part of the apparatus by means of Fig. 368.

A is the metal disc which has the dial: twenty-six teeth on the circumference correspond to twenty-six divisions, and serve as stopping places for the handle. On the axis O O′ is fixed a toothed wheel RR, which works into the pinion H. When the wheel turns through $\frac{1}{26}$ of

the circumference, that is to say when the handle passes from one letter to another, the pinion makes half a revolution, and also the

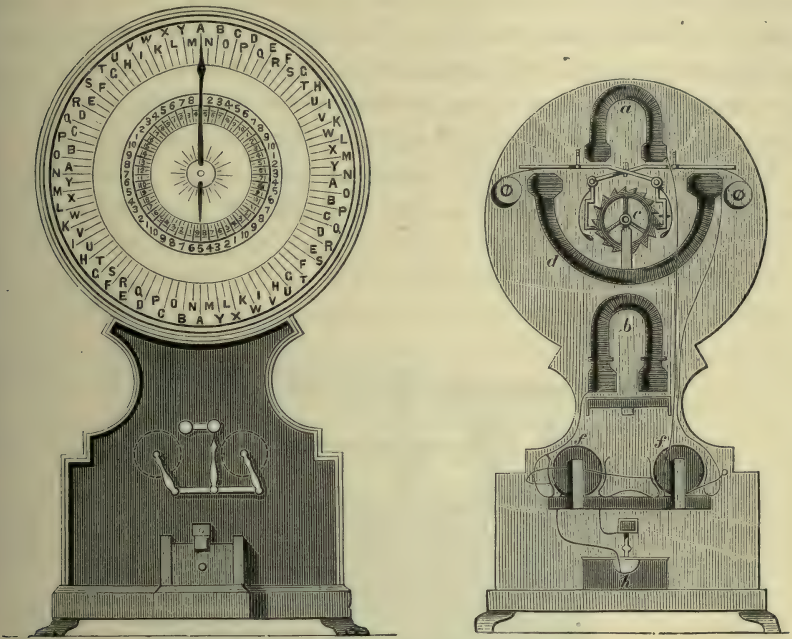


FIG. 366.—Nott and Gamble's letter-telegraph, 1846.

cylinder CC. On the iron column BB are fixed by similar poles the permanent magnets *a a a* ranged in two series, one presenting to the

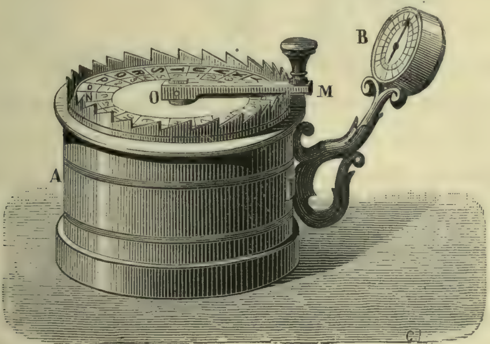


FIG. 367.—Siemens' and Halske's dial telegraph.

cylinder C the north-seeking pole on one side of the cylinder, and the other series the south-seeking pole on the other side; and it is by

turning on itself and presenting alternately first one and then the other side, separated by the coil, to the poles of the magnets *a*, that the induced currents are developed which are successively thrown into the line. For each revolution of the cylinder C two currents are produced in opposite directions. It remains to show how these currents produce in the indicator corresponding motions of the indicating needle, and this may be easily understood from Fig. 369.

It represents the receiving mechanism placed below the dial plate of the indicator. M and M′ are the two coils of the electro-magnet

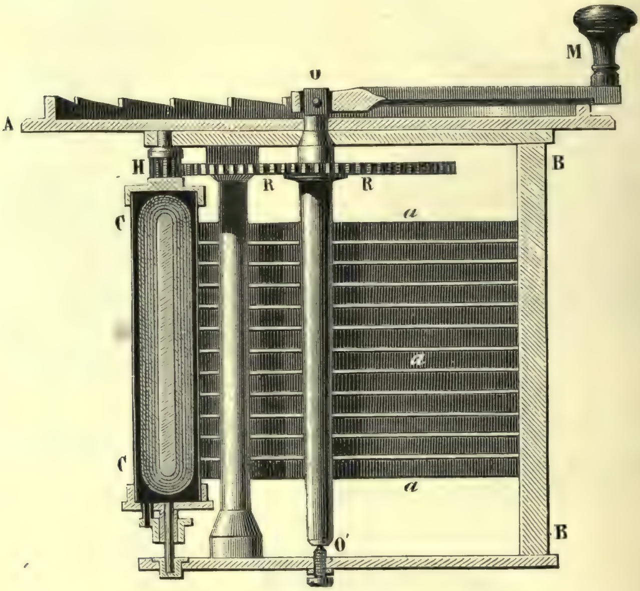


FIG. 368.—Manipulator of Siemens' and Halske's dial telegraph.

which is excited by the currents in opposite directions sent along the line; P and P′ are the two poles of that electro-magnet. Between these poles passes the branch of a fork of soft iron *abb′*, which is constantly polarized by contact with the poles of the permanent magnet AA′. It follows that, according to the direction of the current sent, the branch *a* is sometimes attracted by the pole P and repelled by P′, and sometimes attracted by P′ and repelled by P. These oscillations, twenty-six in number, when the handle of the manipulator makes a complete revolution, allow at each movement the escape of one of

the twenty-six teeth of the wheel R, and consequently the advance by one division of the dial needle, which is mounted on the same axis as the wheel.

In Froment's dial telegraph, Fig. 370, the indicator differs in no respect from that of Bréguet's. But the manipulator is distinguished by a particular method of transmitting and interrupting the currents. In this instrument an undulating groove determines by its rotation the oscillations of the lever A, one of whose branches works in it. It is easily understood then, without further detail, how the other branch of the oscillating lever serves to commence and interrupt the successive currents. What requires explanation is the manner in which M. Froment has arranged this transmission of motion so that the number of current emissions may be that which corresponds to the position of each signal on the dial.

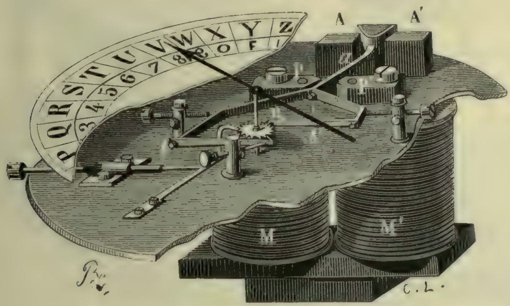


FIG. 369.—Indicator of Siemens' and Halske's telegraph.

A clockwork arrangement moves the wheel B. But for this movement to take place the tooth on the circumference of that wheel must be disengaged from the catch E by which it is held in place. This disengagement is accomplished by the action of a key-board, each of whose keys corresponds to a letter or a number. By depressing one of these keys the catch is moved by a bar which raises it, and the rotation of the wheel commences under the influence of the clockwork with a velocity of two or three turns a second. Below the key-board is a metal axle, or cylinder D E, which turns with the wheel B, and on the same axis. This axis has as many pegs as there are keys, forming two series arranged in spirals; each peg corresponds to one of the keys, and its angular position on the cylinder depends on the

order of the corresponding letter on the dial. Underneath each key is a tooth, which when the key is pressed down juts against a corresponding peg as soon as the angle of rotation corresponding to the latter is described. At this moment the motion stops, and the number of transmissions and interruptions of the current effected is, as we have seen, dependent on the order of the key or the letter. The needle of the indicator has then passed over the same number of divisions, and is then stopped at the letter sent. The key being let go the catch *e* is lowered—the tooth of the wheel B is held again until another key being pressed down disengages it, and starts a fresh rotation and fresh stoppage.

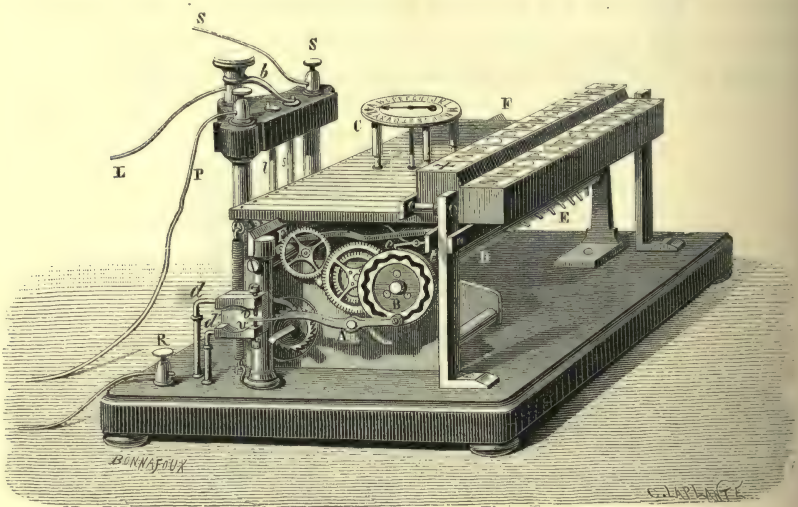


FIG. 370.—Froment's dial telegraph; manipulator.

Above the key-board is a dial whose needle moves with the transmitter and serves as a check to the clerk who sends off a message.

M. Froment has constructed apparatus on this system which work without clockwork movement. Those which possess this mechanism for motion are constructed for working long lines. But all of them according to the unanimous testimony of competent judges, work with surprising precision. Whatever may be the movements, says M. Du Montcel, which are executed on the key-board, in whatever way the keys are pressed down, as soon as the finger rests on one of them the corresponding letter appears on the dial.

§ VI.—Wheatstone's Magneto-Alphabetical Telegraph.

One of the most perfect forms of the step by step letter-showing telegraph is Wheatstone's magneto-A.B.C. instrument, which has since 1860 come into general use for short private wire telegraphs between offices and works. The apparatus consists of three distinct parts, the "communicator" for sending the message; the "indicator" for receiving the message, and the "alarum" for calling attention.

The "communicator" consists of a powerful horse-shoe magnet, with four coils of insulated wire wound round soft iron cores attached to the poles. A soft iron armature is made to revolve rapidly in front of the soft iron cores of the coils by means of a handle and multiplying wheels, so that by the successive "make and break" of the revolving armature before the poles of the magnet, currents of magneto-electricity in alternate directions are rapidly generated, and in readiness to be passed into the line wire in any consecutive number of alternating currents which may be necessary to indicate a signal. Over the magnet is a fixed dial furnished with the letters of the alphabet, and other signs arranged round in equal spacing. Finger buttons attached to lever-keys are placed round the dial, each button being opposite to, and corresponding to a letter or sign; by a simple mechanical contrivance, a circular slack chain is placed in connection with the levers of the buttons, so that when any key is depressed by the finger it draws up the slack and remains down—while the rest of the chain being tightened elevates the lever of the previously depressed button. If no key is depressed down, the alternate currents developed by the rapid "make and break" of the revolving armature before the poles of the magnet, will pass continuously into the line wire, but if a button key be depressed, the end of the key-lever will be thrown forward, and arrest the revolution of a rotating arm set in motion by the gearing of the armature, and the flow of the alternating currents into the line wire will be cut off. Thus by the successive depression of the necessary buttons by the finger, each button as depressed raising the one previously depressed and releasing the rotating arm, alternating currents flow into the line until the arm is again arrested by a depressed button, and the number of these alternating currents corresponds

automatically with the number of letters or signals between the signal button releasing the arm and the signal button at which the arm is once more arrested. If therefore the index-pointer of the communicator is at zero on the dial, and the next finger button opposite A is depressed, one current passes into the line, and A will be shown on the distant dial: the button opposite the letter N being now depressed the A button rises up and liberates the revolving contact arm, and 13 alternating currents pass into the line, the arm cutting off the currents again by contact with the lever of the N button: the D button being now depressed the arm is again at liberty to rotate, and 17 alternating currents are passed into the line before its motion is arrested at D; thus the pointer on the dial of the indicator of the distant instrument which also stood at zero, will have advanced one space, showing A, then step by step 13 spaces, stopping at N, and again 17 spaces to D, indicating the word "AND." The "indicator" consists of a delicately poised magnetic bar armature which is caused to oscillate between the poles of four magneto-electric coils by the alternating currents passed through the coils from the communicator; the axis of this armature carries a lever and very delicate escapement wheel, to the axis of which is attached a pointer which rotates over an external dial corresponding with the dial of the communicator, as this escapement wheel oscillates between two fixed stops, it is impelled forward in one direction step by step, and two hair-spring detents at each movement lock the wheel, securing a dead beat motion to the index-hand over the dial, thus the alternating currents passed from the communicator are reciprocated in the oscillations of the armature and escapement arrangement of the "indicator," the index pointer of which is arrested at the particular letter which the depressed button of the communicator at the distant station represents.

The "alarm" in its mechanism is a modification of the oscillating magnetic armature and electro-magnetic coil arrangement of the indicator, releasing a detent, and clockwork causing a hammer to strike a bell.

CHAPTER IV.

ELECTRIC TELEGRAPHY (*continued*).

§ I.—WRITING TELEGRAPHS.—THE MORSE AND MORSE-DIGNEY TELEGRAPH.

THE needle and dial telegraphs just described form a pretty numerous system, each of which has its own advantages and drawbacks. In the first, which are very simple in construction, a feeble current is sufficient, but they are very susceptible of disturbance. The second class, the mechanism of which is far more complicated, have the advantage of being easily worked after only a short apprenticeship. Both of them, however, are subject to a grave defect, they leave no trace of the message sent to control its correctness, in case of a false interpretation, interruption or fraud.

The Morse telegraph which dates from 1838 is the type of the writing telegraphs. The universality of its adoption on the great majority of telegraphic lines is justified by the simplicity of its mechanism and the certainty of its indications. We will first describe the Morse apparatus itself, and will then indicate the modifications it has received—to the notable improvement of the signals.

The manipulator is represented in Figs. 371 and 372. It is composed of a wooden base on which are fixed two binding screws, *b* and *d*, and in the middle a short forked column, between the branches of which a lever A can oscillate in a vertical plane. To the screw *d* is attached the wire P which comes from the positive pole of the battery; *b* communicates with the wire R which ends in the indicator and the column in the middle receives the line wire L. The lever A is provided, at each of its extremities, with two screws *a* and

c each of which may be put in contact with the corresponding screw *b* and *d* below it.

In the position of rest, or while waiting, the spring *f* keeps the screw *c* out of contact with *d*, and then the screw *a* touches *b*. This is the position for receiving, for as soon as a current thrown into the line reaches the station it passes from L into the lever of the manipu-

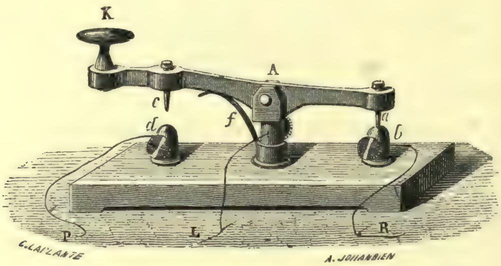


FIG. 371.—Morse's manipulator.

lator and by *a* and *b* into the indicator. If on the contrary, a message is to be despatched, that is, a series of discontinuous currents, the clerk has only to press upon the wooden handle K of the lever, so as to overcome its resistance—to separate *a* from contact with *b*, and to bring *c* on the contrary in contact with *d*. As soon as this last contact is made a current passes from P into the manipulator and from thence

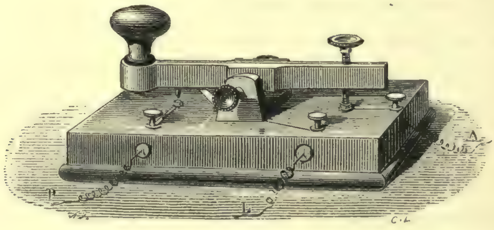


FIG. 372.—Another pattern of Morse's manipulator.

into the line wire L. The current sent is interrupted when the contact ceases. Nothing is more simple, as we see, than the Morse manipulator of which Figs. 371 and 372 represent two patterns.

The indicator is not much more complicated. It consists of an electro-magnet whose magnetising coil forms on one side a continuation of the line-wire, and on the other passes to earth. The series of

currents thrown into the line by the sender, magnetizes and demagnetizes the soft iron of the electro-magnet in the same order, and with the same alternations and for the same duration as the signals of the manipulator. The soft iron armature of the indicator in the form of a lever, is attracted and then drawn back into its position by an opposing spring or repelled when the current ceases. This lever oscillates about a horizontal axis and is limited in its oscillations by two screws. The end of it away from the poles of the electro-magnet carries a point which presses against a band of paper, and leaves there a discontinuous mark whose length is proportional to the duration of the current. The intervals between these marks are on the contrary

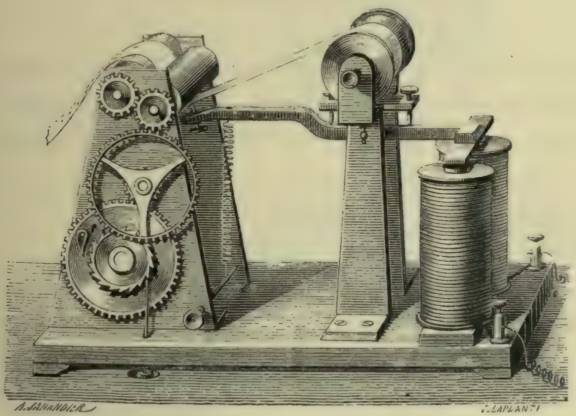


FIG. 373.—Indicator of the Morse telegraph.

so much the longer, as the continued interruption of the current is greater. A clockwork arrangement, which can be put in motion at pleasure by means of a catch, continuously unrolls some paper that is rolled upon a cylinder, and rolls it on to two other cylinders as soon as the style has described upon it the series of marks which constitute the message.

At first, the lever of the indicator was provided with a pencil, the point of which traced the marks on the paper, but the point soon wore down and for that reason the inventor has substituted for the mark of a lead pencil the scratching produced by a metallic point. But in truth this latter method requires a force that the current of the

line-wire is generally too weak to produce—hence the necessity of employing at the receiving station a local battery and a relay.

A *relay* is a supplementary apparatus for strengthening the current

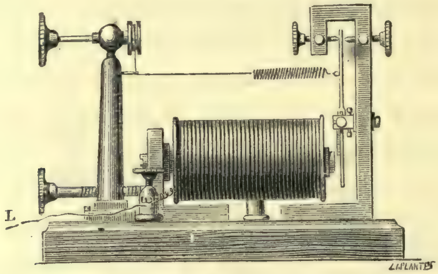


FIG. 374.—Froment's relay.

in the line-wire, when it is sufficient to transmit signals, but not sufficient to produce the permanent mark on the paper. We can see what part a relay performs by following in Fig. 375 the course

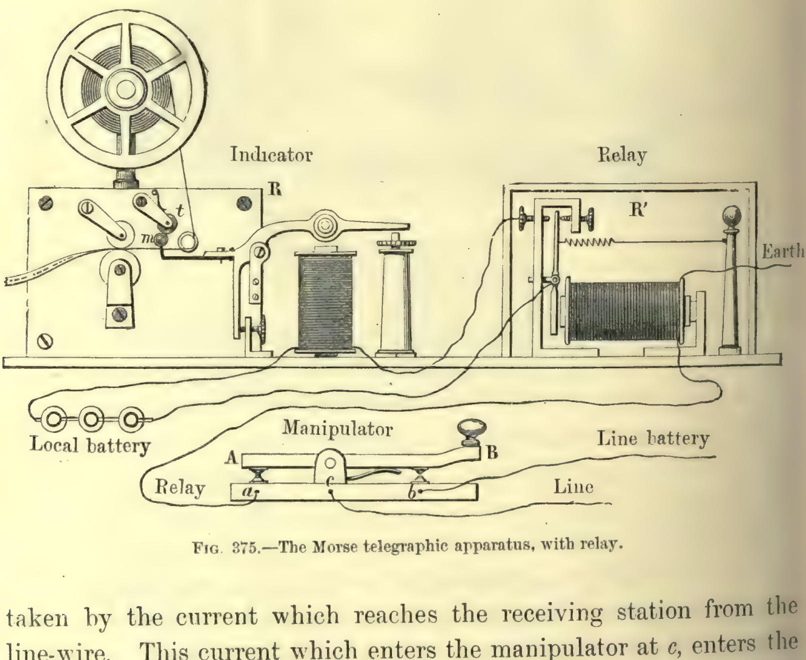


FIG. 375.—The Morse telegraphic apparatus, with relay.

taken by the current which reaches the receiving station from the line-wire. This current which enters the manipulator at *c*, enters the relay R′ at *a* and passes to an electro-magnet which is polarized by

its action. The armature, or light lever, is attracted and comes in contact with the left hand screw, giving passage to the current which passes on to the bobbin of the indicator, at the same time closing the circuit in the local battery. The action of this latter battery is thus added to that of the line-current in moving the writing lever of the indicator R. When the line-current is interrupted, the polarization of the electro-magnet of the relay ceases, the armature is brought into contact with the right hand screw, and the circuit of the local battery

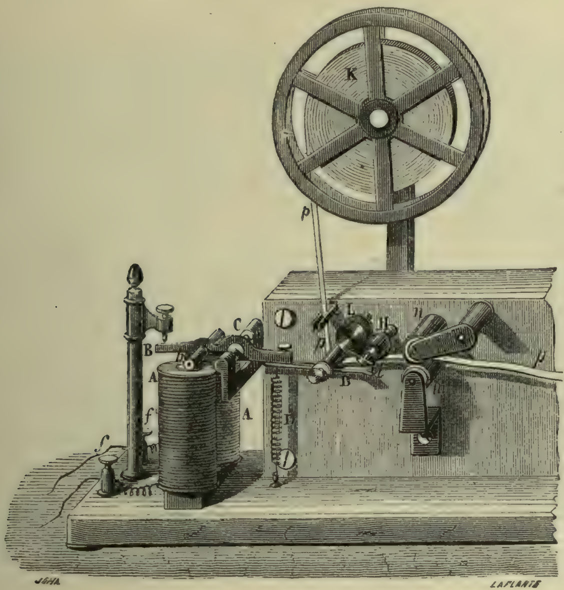


FIG. 376.—Indicator of Morse-Digney system.

is left open at the same time that the indicator ceases to receive any line-current.

There are different systems of relays; the one represented in Fig. 375 and separately in Fig. 374 is due to M. Froment.

The indicator of the Morse telegraph, as worked on the telegraphic lines of England and France, at least, has been modified and improved by Mr. Digney, by substituting for scratches, marks made with ink which require less force in making. For this reason the Morse-Digney system requires no relays for working. Figs. 376 and 377

give its general arrangement as well as the essential details. We will follow the details of Fig. 376.

K is a long roll which furnishes the band of paper *p p p* destined to receive the message—and which is turned by the clockwork of the indicator. The same clockwork turns the cylinder H against the ink pad L which is charged with thickened ink. BB′ is the lever which is set in action by the passage of the current and whose point *l* presses the paper against the inked cylinder. The dot or dash which in the ordinary Morse system was marked on the paper itself

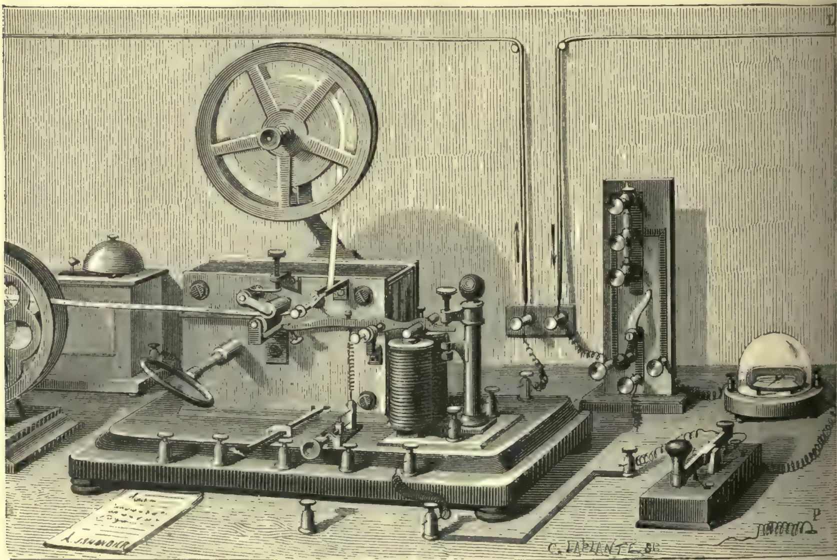


FIG. 377.—Telegraphic station on the Morse-Digney system.

is now simply traced with ink; it leaves a more visible impression, while it requires, as we have said, less force to produce it.

The Digney apparatus can do without relays if the line is of no great length. When, however, the line is long, they may be used, as also for sounding the alarum, an instrument which is common, as may be easily supposed, to all telegraphic systems. Fig. 377 represents the interior of a telegraphic station on the Morse-Digney system. To the right is seen the manipulator, which communicates with the galvanometer and the lightning conductor. In the centre is the

indicator, whose clockwork motion is provided with a key for winding up, to the left at the back is the alarum.

We have already said that the Morse system is adopted on a great number of telegraphic lines in Europe, and is in general use throughout America. By virtue of a generally adopted convention the vocabulary of this system for letters, figures, stops, and special signals, is that shown in Fig. 379. In Fig. 378 is reproduced the facsimile of a message and its translation into the ordinary alphabet.

An automatic form of Morse transmitter has recently been introduced by Messrs. Siemens, which unites the two functions of composing and transmitting messages automatically by means of a single apparatus. The sending of a message is caused by pressing down finger keys each of which corresponds to a letter, and the message is received in the Morse character, the difference of the length of these signs being independent of the time the finger keys are

FIG. 378.—Facsimile of a Morse message.

pressed down. The transmitting speed of the instrument depends upon the rapidity with which the finger keys are depressed; the apparatus is capable of transmitting 90 messages an hour of 33 words each. In construction the instrument consists of a cylinder wheel the periphery of which is fitted with sliding pins placed close to each other and parallel to the axis of the cylinder; these pins when pushed at one end by means of a lever attached to the finger key are deplaced in the direction of the axis, and groups of deplaced pins in certain combinations constitute the various types for the automatic transmission of the signals, three deplaced pins in close succession represent a *dash*, and a single deplaced pin between two in their normal position a *dot*, while one or more not de aced signify an interval of more or less length.

Thus upon pressing down a finger key a group of pins is deplaced

MORSE ALPHABET.

a	- —	o	— — —
ä	- — - —	ö	— — — -
b	— - - -	p	- — — -
c	— - — -	q	— — - —
d	— - -	r	- — -
e	-	s	- - -
é	- - — - -	t	—
f	- - — -	u	- - —
g	— — -	ü	- - — —
h	- - - -	v	- - - —
i	- -	x	— - - —
j	- — — —	y	— - — —
k	— - —	z	— — - -
l	- — - -	w	- — —
m	— —	ch	— — — —
n	— -		

FIGURES.

1	- — — — —	6	— - - - -
2	- - — — —	7	— — - - -
3	- - - — —	8	— — — - -
4	- - - - —	9	— — — — -
5	- - - - -	0	— — — — —

MARKS OF PUNCTUATION, AND OTHER SIGNALS.

. ...	- - - - - -	dash ...	— — — — — —
, ...	- — - — - —	begin ...	— - — - — - —
;	— - — - — -	understood	- - - — -
:	— — — - - -	mistake ...	- - - - - - - - - -
?	- - — — - -	finis ...	- — - — - — -
!	— — - - — —	wait ...	- — - - -
-	— - - - - —	telegraph	- - - — - - -
'	— — — —	received...	- — - - — - - — -

FIG. 379.—Vocabulary of the Morse System.

from their normal position upon the circumference of the cylinder corresponding to the particular letter of the alphabet represented by the depressed key. The cylinder, upon the depression of each key, rotates to an extent corresponding to the length of the signal given, and the deplaced pins in their protruding position are carried round with the cylinder, causing contacts to be made by which the necessary succession of currents to form the signal are passed into the line-wire.

§ II.—Printing Telegraphs.—Hughes's System.

The various telegraphic systems we have hitherto studied, in spite of their different constructions and methods, have all employed in producing signals a common principle which we can enunciate as follows:—the sending by a dispatching office of a determinate series of currents and of interruptions of currents, which produce at the receiving station a series of movements constituting the preconcerted signals.

The movements of the manipulator and indicator may be the same or not, but it is essential that there should be a relation between them, if not of absolute simultaneousness, at least of synchronism so that there should be a perfect identity between the signal sent and that reproduced. This last condition, the synchronism of the movements of the manipulator and indicator, is quite indispensable also in the Hughes printing telegraph which we are now about to describe.

The idea of getting the message printed is not new. From the origin of the invention of the electric telegraph (1841) Wheatstone patented a system of printing in ordinary letters on a band of paper, the words of a message. Afterwards several inventors have followed the same idea and have realized it with greater or less success: we may mention the systems of Vail, Bain, Brett, Du Montcel, Freitel, Theyler, Dujardin, Thomson, Digney, &c. But the most perfect of all these systems which more than all has solved the problem of great rapidity of transmission is the printing telegraph of the American professor Hughes. It is a more complicated and expensive apparatus than the Morse, more difficult to work and keep in order,

requiring better skilled clerks, but which offers in exchange the very important advantage to lines where a telegraphic communication is frequent, of being able to transmit about three times as fast as the Morse. Hughes's system in fact requires only one transmission of the current instead of three or four for each letter and sign.

Hughes's system offers the peculiarity that when the manipulator of a sending station is worked, the indicator of that station works in the same manner and at the same time as the indicator of the receiving station to which the message is sent, consequently the message is printed at the same time at the two stations, so that a double control is the result. If then we can give a clear explanation of the manner in which this printing is accomplished in the sending apparatus we

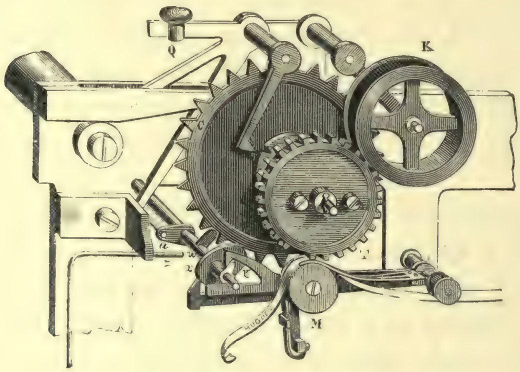


FIG. 380.—Relation between the type-shaft and printing-shaft.

need do no more than show how the synchronism of the movements at the receiving station is secured by the sending and interruption of the successive line currents.

Plate XIX. represents the complete apparatus in which the manipulator and indicator are partly combined. Powerful clockwork put in motion by a weight of at least fifty kilogrammes is arranged on a table in front of which is seen the key board of the manipulator composed of twenty-eight keys, of which twenty-six belong to letters, figures, or other signs marked on their upper surface, and of the two remaining, one is to produce the blanks or intervals between words, and the other to print when required, the sign, figure or signal which each key has marked on it above the alphabetical letter.

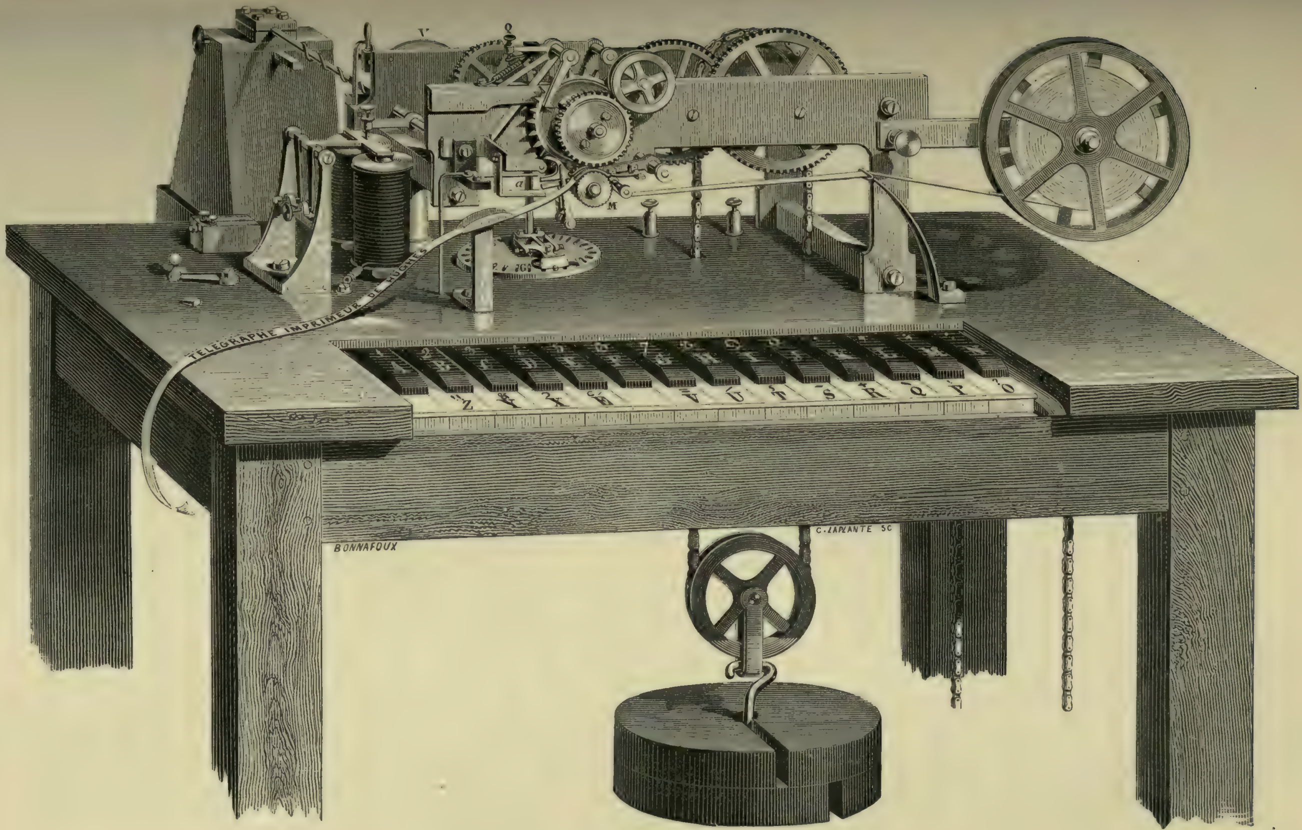


PLATE XIX.—HUGHES'S PRINTING TELEGRAPH.

The clockwork when put in motion turns with different velocities three axes or shafts two of which are horizontal and the third vertical. The first of these axes is the *type shaft* which carries on the outside a wheel T (Figs. 380 and 381) on the circumference of which are engraved in relief the letters of the alphabet, and in the intervals the figures, stops, or other signals required in the composition of a message. Behind the type shaft and on the same axis is the *correcting wheel* T′, whose function is to establish synchronism between the movements, in case either of the indicators should gain or lose upon the other. Two other toothed wheels transmit the motion to two other axes. The second, the *printing shaft,* or cog shaft, turns with a much greater velocity than the type shaft. It carries a series of four cogs, *u w x y* (Fig. 380), whose function we shall come to, one of them being principally for pressing the printing roller *m* against the paper, and the latter against the letters of the type shaft inked by the ink pad K. The second shaft is divided into two parts joined by a catch so that the part whose movement causes the printing does not start till the key of the manipulator key-board is pressed down, and the current produced, and the consequent action of a particular portion of the mechanism affected by the passage of the current.

The third shaft *a,* which is vertical (Plate XIX.) derives its motion from the type shaft by a bevel wheel, and in turning it makes a *chariot* revolve on the horizontal disc G, so as to describe a complete circumference in the same time that the type wheel makes a complete revolution. The disc G is pierced with twenty-eight holes, that is as many holes as there are keys on the key-board and letters on the circumference of the type wheel. Now the motion of the different parts of the mechanism is so arranged, that at the precise moment when the chariot passes over a hole corresponding to a given letter, that letter occurs on the type wheel situated at the lowest part, that is over against the point of the printing roll which is being pressed against it by the action of the printing shaft. But how does the position of the chariot, or the pressing down the key determine the action of this shaft? Fig. 381 will help us to explain this. It is a section taken through the apparatus in the plane which contains the type shaft and the vertical shaft which carries the chariot.

The vertical shaft is formed of two pieces of metal insulated by a cylinder of ivory, and the arm of this shaft which constitutes the

chariot is also composed of two parts v and v' which are joined by a screw V. The piece v when the shaft moves round, passes exactly above the holes in the disc, and so long as it is lowered in the position shown in the figure, the galvanic current reaches the lower part of the shaft, and through the screw V passes away to earth. (See also Fig. 382 of the receiving station.) But when a key is pressed down, its extremity raises a pin g, which in turn raises the piece v of the chariot and insulates the two parts of the shaft a. The current now coming from the positive pole of the battery, follows the path

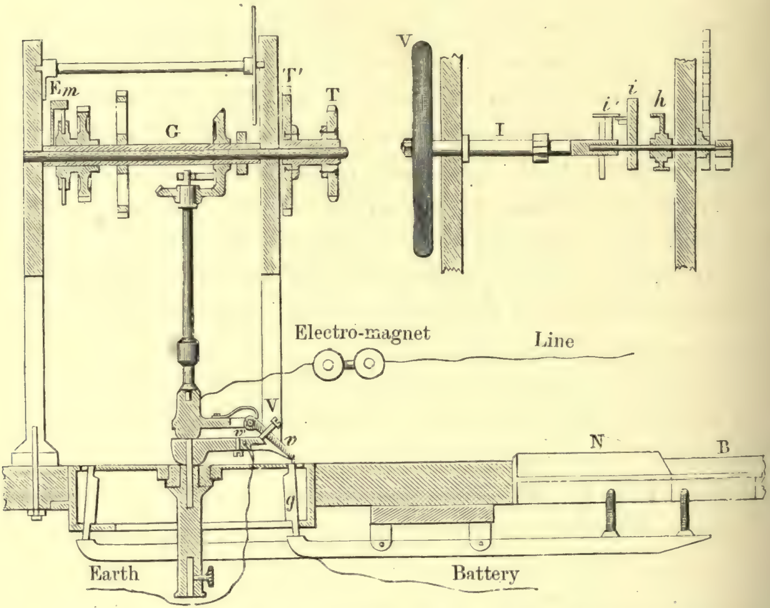


FIG. 381.—Mechanism of the keys—the working of the vertical shaft and the chariot in Hughes's telegraph.

indicated by the arrows (Fig. 382), passing through the points $tGBa$ enters the coils of the electro-magnet E and thence into the line wire L, and so passes on to produce its effect in the apparatus of the receiving station. At each pressing down a key a like effect is produced, and when it is let go the current is interrupted and the effect ceases. So much for sending and interrupting the current. We must now examine what is the alternate action of the current in the sending and also in the receiving apparatus, the movements of which, as

already stated, are absolutely synchronous. The electro-magnet E (Fig. 382) has a special arrangement. It is formed of two pieces of soft iron about which the bobbins are coiled, and which are placed on the poles of a permanent magnet. When no current is passing the tongue of the lever p is attracted by the armatures of the electro-magnet, and presses against them; but as soon as the current passes, since it acts in a contrary direction to the permanent magnetism, the soft iron is demagnetised, the lever p yields to the action of a spring r, and leaves the armatures. In this movement, the tongue raises a lever l which in turn acts upon the catch of the immovable part of

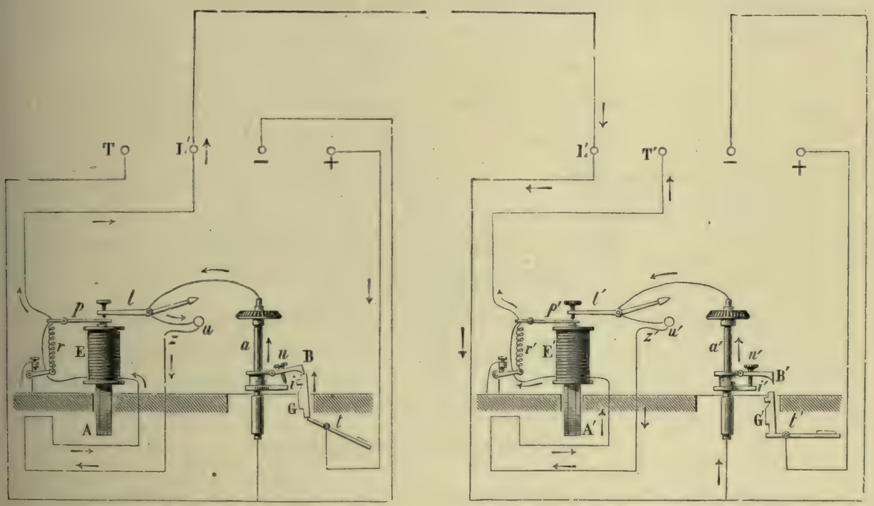


FIG. 382.– Directions of the currents in Hughes's telegraph.

the cog shaft and this latter finally participates in the motion of the other shafts, till after a complete revolution the catch is disengaged and the shaft is stopped.

Let us see then how this shaft causes the printing of the letter corresponding to the key depressed together with the transmission of the current and other effects just described.

The printing shaft carries a sharp cog p (Fig. 383) which at each rotation comes against the tooth b of a lever ab and raises it; this lever thus forces the printing roll M to come in contact with the band of paper against the inked letter of the type-wheel which passes at

the same moment. Now this letter, at each passage of the current, is precisely the same as that on the key pressed down which raised the pin into the hole of the disc D and the piece of the chariot passing above. The letter is printed in passing as we may say, as the type-wheel moves continuously. The three other cogs of the printing-shaft serve as follows: the first in the form of a helix, to depress the lever JU, which carries the catch *r* and moves on the ratchet wheel E by one tooth and so the band of paper; the next cog works in the teeth of the correcting wheel, so as to put right the stoppage, losses, or gains of that wheel, and to preserve the complete accordance between the type wheel and the chariot, and the last cog is to adjust the apparatus to the starting point, that is, the blank space on the type wheel.

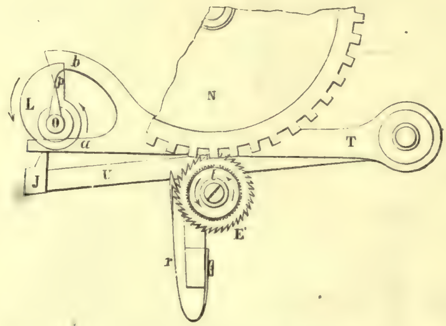


FIG. 383.—Printing machinery in Hughes's system.

The way of proceeding for sending off a message is this: the clerk at the sending station, to attract the attention of the station on the line to which the message is to be sent, raises the break of the fly-wheel of the clockwork and sets it in motion, then he depresses the white key which moves the alarum in the receiving station. The clerk here, on receipt of this warning puts his apparatus in motion, and the two clerks together pressing on the pedal Q regulate their apparatus, that is, put their type-wheels to blank; they then test the synchronism by repeating a certain number of times the same letter, A for example. If the velocity is the same, that letter is always repeated again and again, if not, and the letter before or after takes its place, it shows one is faster than the other. The regulation is

accomplished by means of a conical pendulum regulator or a vibrating plate.

The apparatus being regulated, the sending clerk makes the letters composing the message by depressing the keys in succession, and it is printed simultaneously at the two stations.

We see, by this rather long description, though we have omitted certain mechanical details, that Hughes's printing telegraph is considerably more complicated than those before described. But this complication, necessitated by the many difficulties of the problem to be solved, only serves to make the result obtained more admirable, a result really marvellous, when it is remembered that the rapidity of transmission is three or four times that of Morse's. While with the latter twelve to fifteen words on an average can be sent per minute, Hughes will print thirty or forty in the same time.

Ingenious in mechanism and mechanical detail as the Hughes type printer undoubtedly is, in practice it is not found to be reliable in a variable climate; the loss of insulation from partial rains and other atmospheric changes over a long line, entail such delicate adjustments to secure the synchronism of the sending and receiving instruments that the loss of time from such adjustments is not compensated sufficiently by any mechanical instrumental capabilities, and the Hughes printer has more or less given place to the Wheatstone automatic transmitter.

§ III.—Wheatstone's Automatic High-Speed Printing Telegraph.

In his automatic apparatus Wheatstone has employed a similar principle to that of the Jacquard loom, that is, he weaves his currents rapidly into the line by the previous preparation of an electrical card, having the necessary sequence of currents to form the letters and words composing the message in readiness before it is placed upon the instrument, by which the time occupied in transmitting any number of currents and groups of symbols to represent letters and words is reduced to a minimum, and the delay and cost incident to manual labour in the direct transmission of the message over the wire are avoided. One of the chief problems of mechanical telegraphy is to obtain the greatest amount of speed out of a wire in a given

time, and this speed is regulated by the rapidity with which currents can be transmitted through the wire without coalescing or interfering with each other. Wheatstone's automatic telegraph consists of three parts, one for the preparation of the perforated paper ribbon, by which the succession and sequence of the currents representing the message are regulated; another, the "transmittor," for passing the currents so grouped together into the line wire, and the third, the "receiver," the apparatus for recording and transforming the currents so passed into the line into symbols representing letters, words, and sentences. The message to be sent is first punched out in holes representing the "dot" and "dash" of the Morse alphabet, on a continuous paper ribbon by

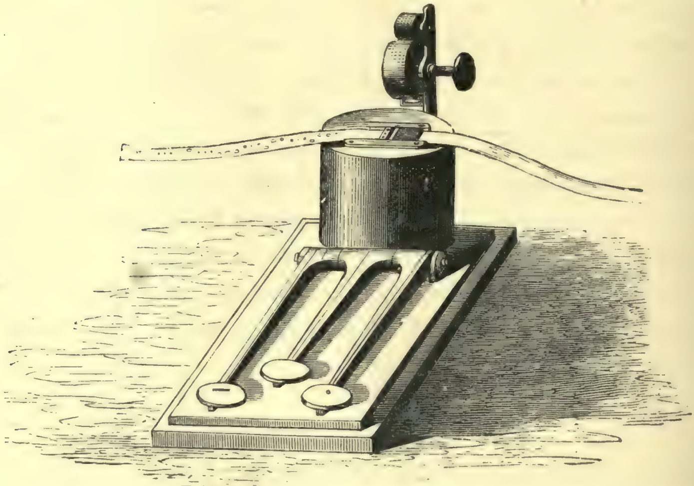


FIG. 384.—The "Perforator," for cutting out the message on the paper ribbon.

means of an instrument called the "perforator," Fig. 384. Each of the three finger-keys on depression perforates certain small round holes in the paper ribbon, the right hand key two large holes opposite each other with a small hole in the middle, being representative of the "dot," the left hand key two large holes alternate over two small centre holes, being representative of the "dash;" the centre key perforates a single centre small hole, this centre hole being for the mechanical spacing of the holes and groups of symbols; it is also necessary for ensuring the regular motion of the paper ribbon through the "transmittor."

When a message is being punched, each depression of a key besides punching the hole, also mechanically moves the ribbon forward the exact space for receiving the next perforation, so that by successive depression of the respective punches the holes are cut in the paper ribbon in the necessary sequences to represent letters and groups of letters to form words and sentences. The message is thus written and prepared away from the wire. The second part, or "transmitter," is the apparatus which automatically sends into the line wire the sequence of currents, as prepared by the "perforator." The perforated ribbon paper strip is caused to advance step by step through the machine by the successive grip of an oscillating cradle, adjusted so as to advance the paper at each oscillation a distance exactly corresponding to the spacing of the holes by the "perforator," so that by the action of a rising pin, elevated and depressed alternately at each to-and-fro motion of the rocking-frame, the message ribbon is automatically and mechanically impelled forward. Two other spring "contact" pins representing respectively the contact with the positive and negative currents are actuated by the same mechanical movement. When therefore the perforated paper ribbon is carried automatically forward step by step in rapid succession by the action of the central pin, if a "current-passing" perforation in the paper ribbon is

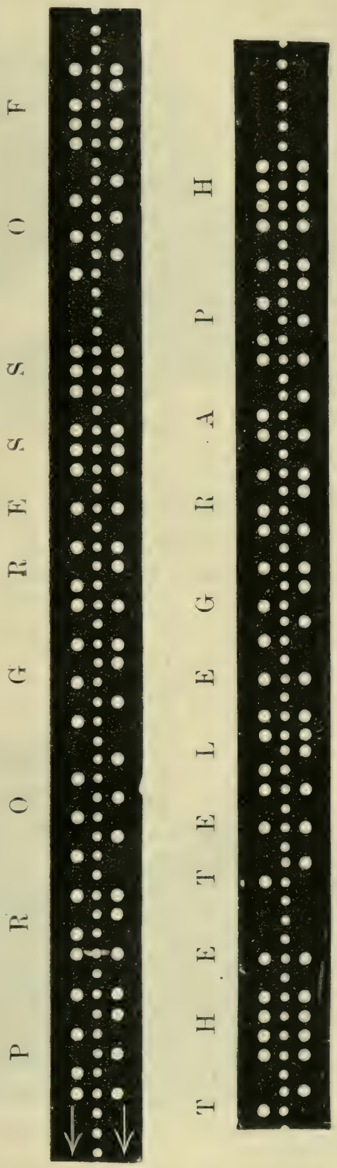


FIG. 38[illegible].—Perforated message on paper ribbon.

in position with either pin at the moment of passing, the respective pin will rise through the hole and make a metallic contact with the

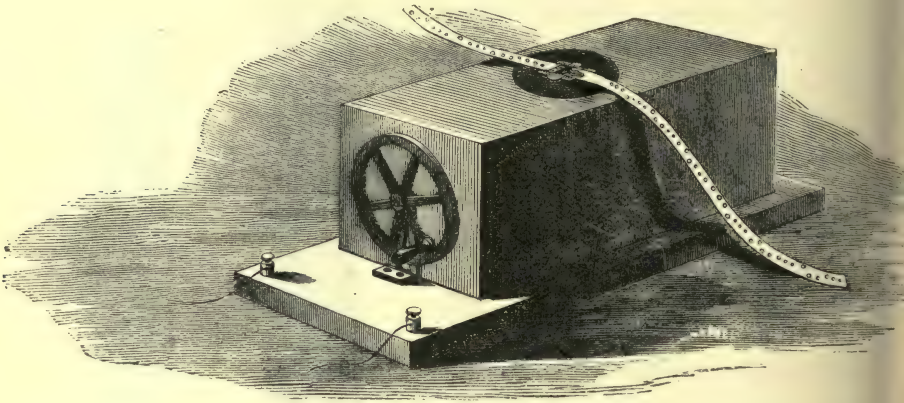


FIG. 386.—Wheatstone's automatic "transmitter."

battery, sending a current into the line in one or other direction, according to the position of the perforation, and the rising of the respective pin. If no perforation in the paper ribbon is in position at

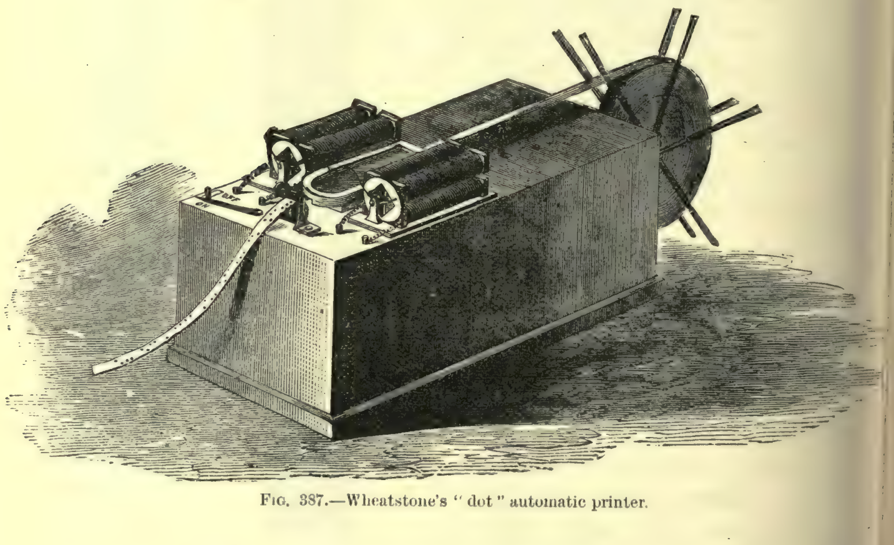


FIG. 387.—Wheatstone's "dot" automatic printer.

the time of the automatic elevation of the respective pins, they fall back by the compensating influence of adjusting springs, and a "mute"

movement is made by which no current is passed into the line wire. At each motion of the rocking cradle, a momentary contact is made between the line wire and the earth, so that after each successive elevation of either current-passing pin, the line is discharged to earth; thus the line is connected for discharge at regular intervals, irrespective of its charge by the elevation of a pin, a current only passing into the line by the contact made with the battery on the elevation of either pin.

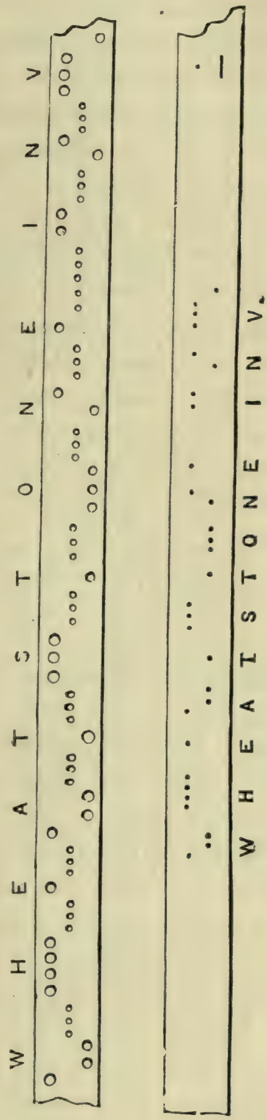


FIG. 388.—Perforated ribbon and printing by Wheatstone's "dot" automatic system.

This discharge to earth to clear the line, especially on submarine wires, is necessary from the sensible retention in the insulated wire of a portion of the transmitted current, which unless drawn out would interfere with the integrity of the succeeding current, and reduce the transmitting speed of the wire. In this mechanical arrangement therefore, the necessary contacts with the battery and the regular discharge of the line are produced automatically and mistakes are avoided. The "receiver," or apparatus for recording at the distant station the rapid sequence of currents passed into the line wire upon a paper ribbon in the Morse code, will now be described. Fig. 387 represents the Wheatstone "dot" receiver, in which the lower line of dots is read off as "dashes," and the upper line of dots as "dots." The paper ribbon mechanically advances forward and passes under a shallow dish containing the ink; two fine holes are made in the bottom of this reservoir in a position to correspond with the two lines of dots to be printed upon the paper ribbon as it passes underneath the reservoir.

By reason of capillary attraction the ink is prevented from passing through these apertures. Two electro-magnetic coils, one on either side of the ink-reservoir, actuate two needles, adjusted so as to be depressed by the action of the current, and dipping into the reservoir pass into the holes and carry a small quantity of ink with them, which is transferred to the paper; thus the action of the current in depressing either needle is printed as a "dot" or "dash" according as the respective needle is depressed, without friction or mechanical resistance. The electro-magnetic coils are so adjusted that only the respective needles are acted upon by the currents as they flow from the positive or negative poles of the battery. The automatic printing in the dot and dash character is shown at Fig. 389. Capillary attraction is here again made use of, only in a different manner. A small inking disc of metal mounted upon a delicately poised axle, capable of a slight angular oscillation in a lateral direction, according as it is influenced by the to-and-fro

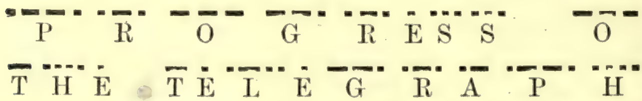


FIG. 389.—Automatic "dot" and "dash" message, printed from the perforated paper ribbon.

motion of a permanent magnetic armature when acted upon by the alternate currents passed into the line from the "transmitter," is caused to rotate rapidly by the same mechanical means that advances the paper ribbon forward. This little rotating inking disc is placed close to the surface of the paper ribbon, so that on receiving a lateral motion in one direction, its edge is pressed against the paper and removed from it by an opposite motion; in its normal position it is free from contact with the paper ribbon. Thus dots or dashes are marked on the paper, according to the length of time, either momentary or of a sensible duration, of the inking contact, the reverse movement of the disc producing the spacing between the printed marks; as the spacings between the signals are automatically regular, the "dash" is the result of the retention of the inking disc upon the paper for double the time of the "dot," by reason of the grouping of the perforations to form the "dash" giving a longer duration without a reversal of the

current being passed into the circuit. The arrangement for supplying the revolving disc with ink is simple. A metal wheel having its edge cut into a V shape revolves in a reservoir of ink, and by capillary attraction this V groove is kept filled with ink, so that the periphery of the little inking disc, which revolves in this V groove of ink, is kept constantly supplied without friction, and is thus enabled to continuously record the rapid motion of the armature as the currents flow into the line from the transmitting apparatus.

§ IV.—Autographic Telegraphs.—Caselli's and Meyer's System.

We have seen that the idea of using the electrolytic properties of a battery for transmitting signals dates from the earliest years of this century. The names of Coxe, Sœmmering and Schweigger are connected with the first attempts. The signals were made in Sœmmering's telegraph by bubbles of hydrogen. In 1839 E. Davy made use of electro-chemical reactions to print signals on a sheet of paper or cloth suitably prepared. Twelve years later Bain constructed a writing telegraph, based on the property of the galvanic current to decompose cyanide of potassium and to produce a coloured compound, Prussian blue, which is deposited on the paper of the indicator every time the current passes and as long as it continues. The manipulating apparatus as well as the indicator was the same as in Morse's. Bain obtained on the band of paper blue points and marks of greater or less length, whose combination furnished the elements of the message. At first Bain made the metal pen of the indicator describe a close set spiral on a sheet of ordinary paper, but the principle was the same.

Other electro-chemical telegraphs have been invented since, but we cannot undertake to describe them. We will only consider those systems or apparatus which are now known as autographic or *pan-telegraphs*, and which have received the sanction of practical use.

It is not the object in this new kind of printing telegraphs to transmit signals which, like the writing telegraphs, may leave traces of the message, or even reproduce it, and print it in alphabetical characters. The problem proposed, and solved with marvellous ingenuity, is to obtain at the receiving station a faithful reproduction or true

facsimile of the written message, or if need be, of drawings, charts, plans, or portraits. It is thus a veritable autograph that the receiver of the message gets from the sender, so as to have in his hands, if required, an authentic document. What could be more extraordinary at first starting than the solution of such a problem? but we shall see that nothing can be easier than to understand the means by which this solution is realised.

Suppose we have fitted in the two stations, the sending and receiving, two plates of copper, M R (Fig. 390), communicating with the earth at T. On the plate M of the departure station is placed a sheet of metallized paper. On this sheet the message is written by the sender himself in greasy insulating ink. At the other station on the plate R is placed a sheet of paper, previously soaked in yellow ferrocyanide of potassium. Two iron styles, S, S′, are connected with the

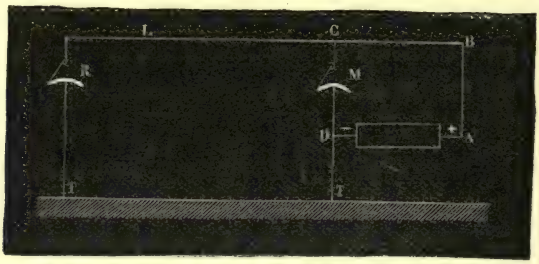


FIG. 390.—Principle of Caselli's autographic telegraph.

battery and the line-wire, and move synchronously, describing with the same velocity very close parallel lines on the two sheets of paper. We shall see further on how these styles are moved, and how their motion is regulated by pendulums which oscillate simultaneously in the two stations. By another motion the sheets are drawn on in proportion as the lines above mentioned are traced, so that when the style S has passed over the entire surface of the plate of the manipulator on which the message is written, the style S′ will have gone over in the same time a precisely equal surface of the chemical paper on the plate of the receiving station.

From the system of electric communication shown in the figure these results follow: all the time the style S is on the metallic or conducting part of the message sheet, the current from the battery is

thrown into the circuit A B C D, which offers a much more feeble resistance than the line-wire, whose length is relatively considerable, and the current passes to the ground at the sending station. The indicator is not influenced, and receives nothing.

When, on the contrary, the style of the manipulator touches the insulating parts, that is, rests on the marks of the writing or drawing of the message, the circuit in A B C D is closed, but it is open in the line, and a current is sent into the style S′ of the indicator. Under the influence of this current the point on the cyanurated paper through which the current passes on its way to the ground is acted on chemically; a decomposition of the cyanide takes place, with a production of Prussian blue, and its impression on the paper. This impression is produced every time the style of the manipulator encounters the parts marked with insulating ink, and the number of marks and their length on each of the lines passed over at the same time by the two styles will be identical at the receiving and sending stations. The message will be identically reproduced on the cyanurated paper in blue marks. The only difference from the original consists in the successive lines not being in absolute contact, and the marks in the message reproduced not being therefore rigorously continuous. The effect is analogous to that produced by the very fine parallel lines with which the engraver in a wood engraving in relief covers all the surface left in relief on the wood. Figure 391 gives a very exact idea of this difference, but we see that the general form of the original message is not at all altered, and that this telegraph has a good right to be called the autographic telegraph.

The telegraph whose principle we have just described is M. Caselli's. Since there is nothing to prevent the reproduction in this way of all sorts of writing, drawings, or any kind of signs, provided they are traced on the proper metallic paper, we can understand the reason of the name *pantelegraph* given to the apparatus of this system.

We may now enter somewhat into detail on the manner in which the preceding arrangements are realized, and on the mechanism of the indicator and manipulator.

The motive power in Caselli's pantelegraph is a pendulum, whose metallic rod of two metres length is suspended from a solid iron framework, the bob being a rectangular mass of soft iron weighing eight kilogrammes. In the middle of the rod two cranks are fixed for

communicating the oscillating motion of the pendulum on one side to the transmitting apparatus, and on the other to the indicator. Since these two apparatus work separately, one of the cranks is detached when the other receives its reciprocating motion, and this crank moves the style on the surface of the transmitter where the message is placed, and in the following manner:—

The crank is itself articulated to the lever that carries the style. In the successive oscillations it makes this lever and the tracing-point describe a series of circular arcs, parallel to each other and to the surface of the cylindrical sheet of metal to which is applied the metallized paper of the message (Fig. 392). When the pendulum makes a complete oscillation, the moving style crosses from left to

FIG. 391.—Facsimile of a drawing reproduced by Caselli's pantelegraph.

right and passes over the whole breadth of the message. At the end of this motion the style comes against a stopper, and the shock turns the rod which carries it, so that it is raised and separated from the paper throughout the whole length of the following oscillation. The apparatus thus only works during one-half of the motion of the pendulum. The reason of this arrangement arises from its having been shown by experience that the effects produced by the oscillations in the opposite direction are not identical, but in order to use these oscillations the transmitting apparatus is double, only the mechanism is reversed, and it is the same for the indicators. The result is that no time is lost, as two messages may one be received and the other sent at the same time.

An essential condition for the satisfactory working of Caselli's pantelegraph is that there should be a perfect synchronism between

the motions of the pendulum of the departure and arrival station. Not only must their oscillations be isochronous, but they must have amplitudes perfectly equal, in order that the styles may move at the two stations simultaneously and have at the same instant the same

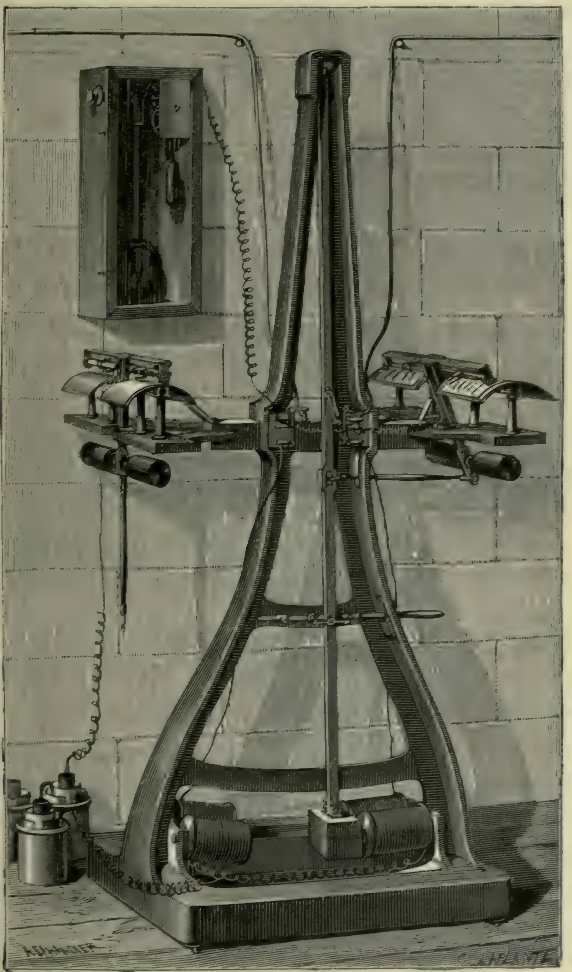


FIG. 392.—Caselli's pantelegraph.

velocities. This result is obtained by the following arrangement. At each extremity of the arc which is described by the mass of iron of the pendulum-bob is an electro-magnet, in the same direction as the

arc, and having its armatures opposite the mass of iron when it arrives at the end of each oscillation to the right or to the left. At this moment a current introduced by a regulating chronometer—seen on the left at the top of Fig. 392—excites the electro-magnet and its armature, which attracts the mass of the pendulum, retains it for an instant, and consequently draws it out, at each oscillation, to the same distance. The interruption of the current is made by the motion of the pendulum of the chronometer, which at each double oscillation separates a little spring and opens the circuit. The commutator, whose business it is to open and close the circuit, also receives its motion from a piece stiffly jointed to the rod of the pendulum.

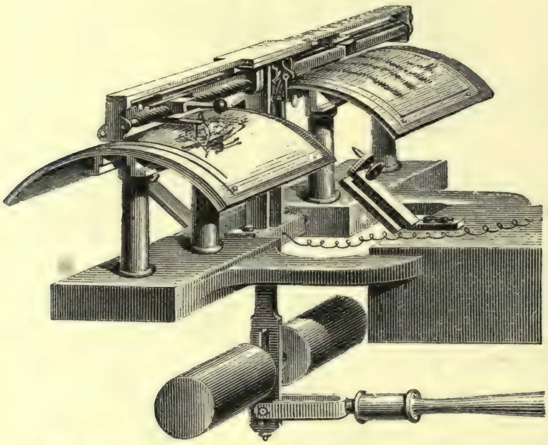


FIG. 393.—Transmitter and indicator of Caselli's pantelegraph.

In this way the regulation of the two pendulums at the departure and arrival stations depends on the concordance of the movements of the chronometer pendulums that accompany them. These regulating chronometers, whose pendulums move with double the velocity of the pantelegraph pendulum, are regulated separately as exactly as possible.

The chemical paper on which the messages are printed must be prepared with care and kept tolerably moist. The quality of the paper itself is important. The metallized sheets on which the messages are written in a particular kind of ink, are made of white paper, carefully silvered and pressed, and having wide margins. They have three boundaries—one being the line from

which the tracer starts, and the other two marking the limits of the message.

Nothing is simpler, now, than the working of the pantelegraph. The message, when written, is placed on the surface of the transmitting cylinder. The clerk makes the warning signals (by alarums or otherwise), and then sets the pendulum going. The transmission of the message is accomplished automatically, without the clerk having any work to do, and consequently without being obliged to acquire any special knowledge. Since two dispatches may be sent at the same time—and since shorthand may be used—the rapidity of transmission may be considerable. "The long pendulums of Caselli's telegraph," says M. Quet,[1] "generally perform about forty oscillations a minute, and the styles trace forty broken lines, separated from each other by one-third of a millimetre. In one minute the extreme lines described by the styles are separated from each other by 13 millimetres and in twenty minutes by 260 millimetres. As we can give the lines a length of 11 centimetres, it follows that in twenty minutes Caselli's apparatus furnishes the facsimile of the writing, portraits, or drawings traced on a metallized plate 11 centimetres broad by 26 centimetres long. For clearness of reproduction, the original writing must be very legible and in large characters."

Since 1865 the line from Paris to Lyons and Marseilles has been open to the public for the transmission of messages by this truly marvellous system.

A clerk in the French telegraph service—M. Meyer—has invented and constructed an autographic telegraph on a different principle to the Caselli pantelegraph, but which also works with remarkable regularity and rapidity, and reproduces the messages sent in facsimile.

The transmitter of Meyer's pantelegraph (Fig. 392) is a cylinder, round which is rolled the message, written in the same way as in Caselli's system. This cylinder receives a uniform motion from clockwork, regulated by a vibrating plate. A metallic style, carried on a little rail, moves in the direction of the axis of the cylinder, on the surface of which it describes a helix or spiral of very low angle. It is connected with the battery and the line-wire, and in consequence it closes or opens the circuit between the two stations in correspondence, according as it encounters, on the metallized paper of the

[1] *Rapport sur les progrès de l'électricité et du magnetisme.*

message, the conducting or insulating parts, that is, according as it touches the silver ground of the paper, or the inkmarks of the message. As far as this goes, except the difference in the kind of motion, the principle of transmission is the same as in the pantelegraph described above.

The receiving apparatus is composed of a cylinder which has a

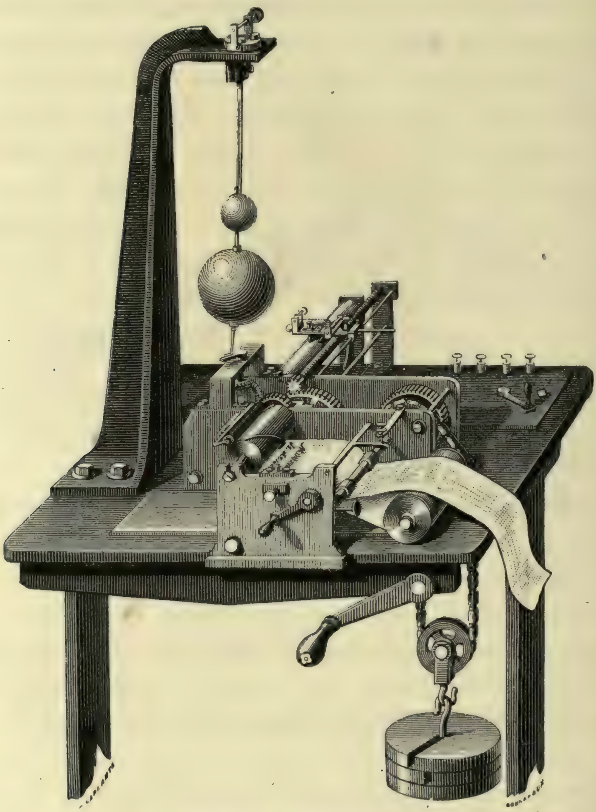


FIG. 394.—Meyer's pantelegraph.

motion of rotation absolutely identical with that of the transmitting cylinder. While one makes a complete turn, the other does also and with the same uniform velocity. Now on the surface of the receiving cylinder is a raised helix which passes round the whole length, a complete turn of which is precisely equal to the length of the circumference of the transmitting cylinder. Now consider a sheet of paper

placed parallel to the lowest line of the receiving cylinder and a little distance below it, and suppose the apparatus at work. Every time that the current passes along the line, that is, as often as the style of the transmitter encounters the insulating parts or the lines of the message, the paper is raised by the motion of a tongue and is applied against the point of the raised helix which happens to be at that moment on the lowest line. During the complete turn described simultaneously by each apparatus, this contact is made and broken as often as the tracing style encounters or leaves the marks of the message. Now the raised helix being constantly damped with thick ink from a roller, the result is a series of points or black marks on a straight line across the breadth of the paper, reproducing identically the figure of the line encountered by the tracing style in one turn of the message. Since the paper moves on the cylinder, so as to advance at each turn by a quantity equal to the intervals between the spiral turns of the style, there will be at last on the receiving sheet a succession of marks which together will give us a facsimile of the message.

Like Caselli's telegraph, Meyer's requires a perfect synchronism of the movements of the apparatus in the departure and arrival stations. The whole question is consequently to regulate the clockwork which moves the apparatus. We perceive that if Caselli's apparatus is a combination of Bain's electro-chemical telegraph with a particular mechanism, the synchronism of which is regulated by electricity, Meyer's apparatus may be considered as a combination of Caselli's telegraph with certain parts of Morse's and Hughes' system.

CHAPTER V.

TELEGRAPHIC LINES.

§ I.—AIR LINES.—SUBTERRANEAN LINES.

WE have hitherto spoken of the apparatus which serve to produce or receive the signals. It now remains for us to describe the lines which transmit them, that is give passage to the electric currents, which are the bases of telegraphy.

An air line of the electric telegraph is formed of metallic wires generally supported by wooden poles planted at equal distances along the course of the line. At first these wires were of copper of 2 mm. in diameter. The metal chosen had the advantage of being a very good conductor of electricity, but besides its high price, it had the disadvantage of losing its elasticity under the influence of changes of temperature and of becoming brittle. Copper having been generally abandoned, annealed iron has taken its place, which though more resisting, is less costly, and to which a diameter of 3 or 4 millim. is given. On lines of over 200 miles in length, where it is required to have as little resistance as possible to the passage of the currents iron wires of 6 or 6½ mm. diameter are employed—chiefly in England.

The iron wires of telegraphic lines are galvanized, that is to say after being cleaned in acidulated water, are covered with a thin coating of zinc; the latter is oxidized in the air, and preserves the iron from rust, and further prevents, by an electrical action, the oxidation of those parts which are accidentally uncovered.

The supporting poles, made of pine, injected with sulphate of copper, are insulating when dry; but to prevent the loss of electricity in damp and rainy seasons, the wire is never directly attached to the poles, but is insulated by glass, earthenware, or porcelain insulators.

Figs. 395 and 396 show how these insulators are arranged on the poles, and how they hold the wires, in the straight parts of the

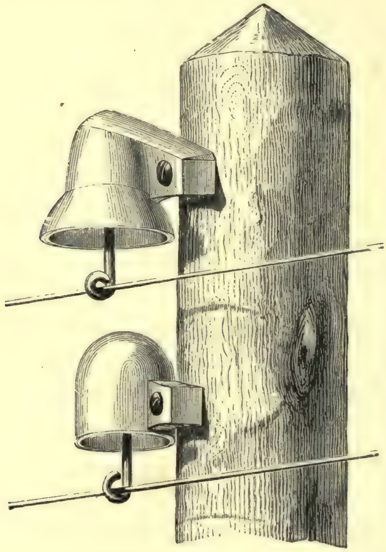


FIG. 395.—Telegraphic air lines; suspending posts; insulators.

line or at points where sharp turns are made, and special arrangements (annular supports) are required.

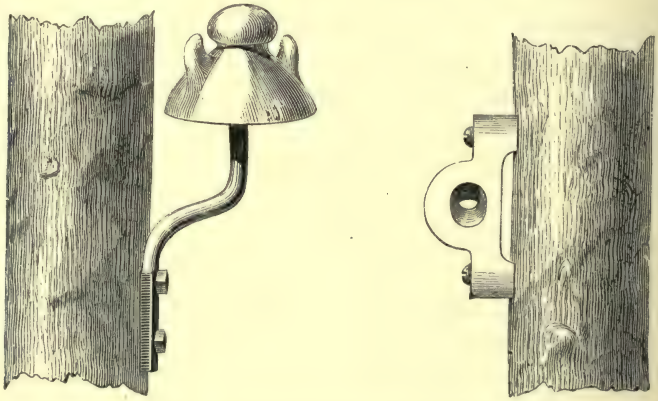


FIG. 396.—Mushroom insulators; annular insulator.

The poles are set up about 60 or 80 yards apart, according to the weight of the suspended wire; they are placed nearer in curves, and

further apart in valleys where the wires may sometimes extend to a length 4 or 5 times as great from pole to pole. The height of the poles is from 6 to 12 yards, but is greater when the line has to clear rivers, roads, &c. In towns, the porcelain insulators are placed on wooden uprights fixed to the walls of houses or other buildings, and sometimes on posts above the roofs; but for many years, it has been found preferable in carrying wires through crowded cities and thoroughfares to replace them by subterranean ones, which are also made use of in tunnels.

Each post generally carries several wires, which are fixed at intervals of about 9 to 12 inches, putting them alternately in front

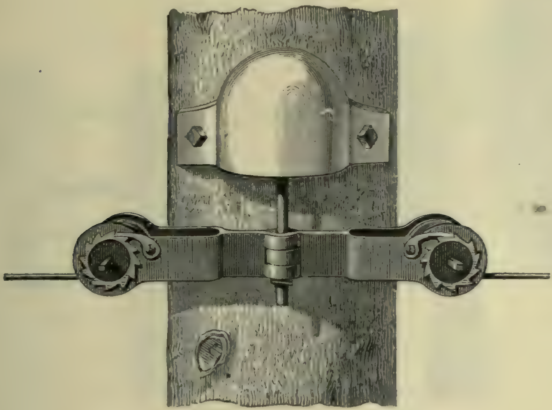


FIG. 397.—Stretching winches for telegraphic lines.

and behind, so as to counterbalance the effects of traction, which tend to bring down the post. Every now and then along the line (at every kilometre in France) are placed stretchers insulated as before by being suspended from insulators, a band of iron joining the two stretchers conducting the electricity between the two wires (Fig. 397). This stretching of the wires is necessary to prevent them from touching and entangling.

In England and Germany other methods of stretching the wires are employed, which may be gathered from Figs. 396 and 397 without further details.

At the outset of electric telegraphy, the system of suspension of

wires in the open air was not trusted to, because it was thought it would be subject to too frequent causes of loss of electricity, and would, besides, be liable to wilful damage. In Prussia particularly and in Russia, the wires were buried in the earth at a depth of 50 to 60 centimetres. But this system of telegraphic lines was found to be very expensive. It is only used now, as we have just said, in those portions of the lines which pass through the middle of towns or through railway tunnels. In these cases the various conductors are arranged as follows.

The wires are of copper, each covered with a layer of gutta-percha,

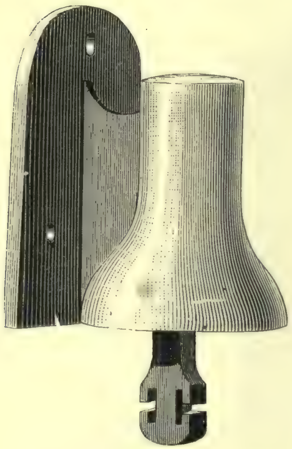


Fig. 398.—English stretcher: Siemens' and Halske's system.

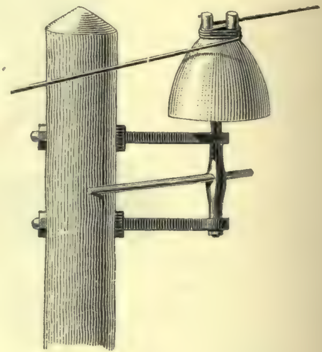


Fig. 399.—Stretcher on German lines.

and all bound together into a cable, which is itself surrounded with tarred hemp. This cable is then placed in an iron tube, or one of creosoted wood or lead, and is buried at a depth of about a yard, on a bed of sand or sifted earth. Such is the nature of the subterranean lines which join the central telegraph office at Paris with the Observatory, the Luxembourg, and the stations of Montparnasse, and the Lyons and Orleans railways, and connect the Central Telegraph Station, London, with the numerous branch offices. Another system consists in the employment of galvanized iron wires, like those of the air lines joined in cords of 4, 6, or 10 wires, insulated from each other by masses of pitch. The cable thus formed is laid in

a mass of pitch poured into the bottom of a trench a little more than a yard deep. Such, in Paris, are the lines which join the Central Telegraph Office with the Tuileries, the Louvre, the Hôtel de Ville, the Bourse, the Préfecture of Police, which are only partly worked, as well as a line of 1,200 metres fixed at Bordeaux. This method has given excellent results, but the trenches must be protected from the infiltrations of gas, which will in time alter the qualities of the pitch.

In tunnels also, the wires are placed against the side of the arch, and are protected from damp by a layer of gutta-percha, which unites them into one cable; but it has been found that the insulating covering alters very rapidly from the action of the atmosphere.

§ II.—Submarine and Transoceanic Telegraph Lines.

Can the transmission of electrical currents and of the signals which constitute electric telegraphy, which signals can as we have seen be made by means of metallic wires suitably insulated in the air and the earth, be effected also in water?

This interesting question was answered in the beginning of telegraphy. In fact, in 1839, M. O'Shaughnessy joined telegraphically the two sides of the river Hooghly, in India, by an insulated wire sunk in the river. The following year Professor Wheatstone, whose name is found connected with every progressive phase of electric telegraphy, proposed to join Dover and Calais by a cable. This project was not realized till 1850. About the same time the French engineer Brett, laid a copper wire insulated by a coating of gutta-percha between Gris-Nez and Dover. The cable was broken,[1] but the possibility of telegraphic communication beneath the sea was demonstrated, and a fresh cable was definitely established across the Straits in 1851. Fifteen more years of trials, and of more or less fortunate attempts to solve the problem, in its generality

[1] A few messages (about 400) were sent, but suddenly the wire was silent. A fisherman had caught it in his nets, and could not resist cutting a piece off, which he brought triumphantly to Boulogne, to show this singular marine production with a centre of gold.—W. Huber, *The Telegraphic Network of the Globe.*

followed. But after this the successful laying and working of the immense transatlantic cable in 1857, joining Europe and America, between Ireland and Newfoundland, was the starting point of a prodigious development of the universal telegraphic network. At the present time, the globe is traversed not only across the continents, but in the depths of the sea, by wires which carry everywhere with the rapidity of lightning, the private and public messages of all civilized nations, the length of all combined exceeding 380,000 miles.

We may now give some details with respect to the structure of the cables, and the mode of immersion adopted.

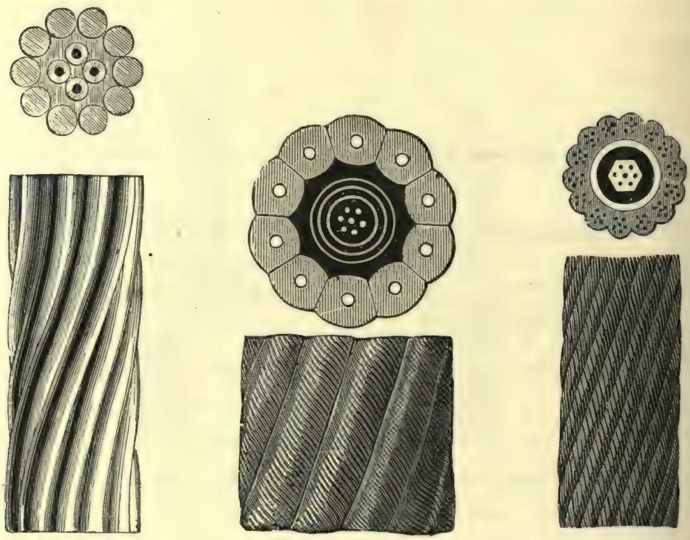


FIG. 400.—Submarine cables—outside view and section.

The conducting wire of a submarine cable is covered with several envelopes, whose object it is either to insulate it, or to protect it against the chances of destruction. It is either a copper wire of 1 or 2 mm. diameter, or a cord formed of seven very fine wires twisted in a spiral. This last arrangement is now preferred as more pliant, because in case of accident or rupture of these inner wires, if one or two of them escape the communication will not be interrupted.

The point of the highest importance is that the wires should be surrounded by an insulating covering of gutta-percha; 3 or 4 layers of

this substance are generally used, of a total thickness of 3 or 4 millimetres. The gutta-percha is not only a very good insulator, but it is almost unalterable in sea-water. At first this was the only covering, but it was soon found necessary to protect it from damage. Round the whole is now placed a thick layer of hemp, saturated with Stockholm tar, and outside this again, the layer is supported and protected by a series of galvanized iron wires twisted in a spiral. The following figures, natural size of some of the cables now working on different submarine telegraphic lines, will

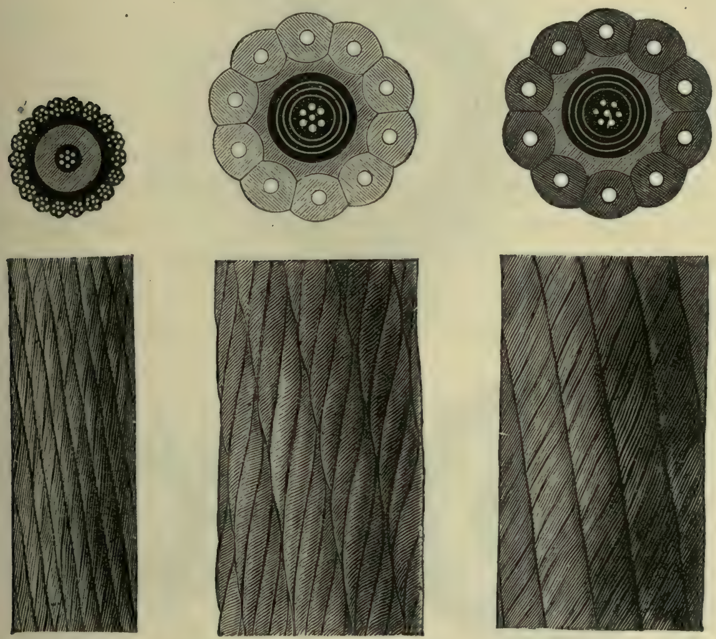


FIG. 401.—Transatlantic cables of the line from Valentia to Newfoundland (natural size).

show these arrangements. We see that though these specimens differ in size, the construction is nearly the same, though in the old cables were placed several distinct wires in order to multiply the communications. This method has been generally abandoned, because of the disadvantages found to be connected with multiple wires; they require in fact a considerable volume and weight in the cable, which makes the operation of laying it difficult, but more particularly the nearness of the wires causes induced currents to be

formed, which interferes with the transmission. It is, therefore, preferred, if the amount of correspondence requires it, to lay several cables between the extreme stations, and for this further reason, that any serious accident happening to one of them generally leaves the other still available.

On the same line the cable differs generally in size according to

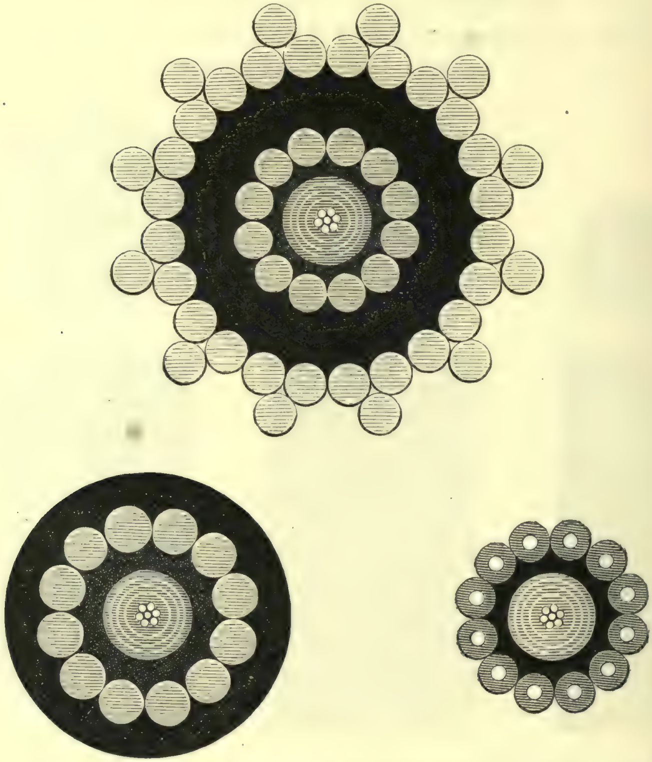


FIG. 402.—Transatlantic cable from Brest to St. Peter's, laid in 1867 (sections of natural size).

the part of the route it is to lie in. Near the coasts, where the sea is shallow and the cable is exposed to accidents arising from the agitation of the sea during storms, the size of the cable is greatest. The metallic element is formed of wires of large diameter, covered with a siliceous compound, for the purpose of increasing its resistance to wearing by friction against the rocks. This is the shore end. For medium depths, a smaller diameter is adopted, both for the cable as a whole and for

the enveloping metal wires. Lastly, for the portion destined to be submerged in the open sea, in very deep water, the smallest size is adopted (Fig. 402), the cable having no longer to withstand the agitations of the surface, and being much more easily laid when of less weight.

This weight is, indeed, something enormous for submarine lines, even if not of great length. The cable from Dover to Calais, laid in 1851, which is only 41 kilometres long, weighed nevertheless more than 180,000 kilogrammes. The first of the transatlantic cables joining Valentia and Brest to America, weighed 865 kilogrammes per kilometre, the second 836. This makes for the total weight 4,300 tons for the first, and nearly 4,000 tons for the second, comprising only the section between Brest and the island of St. Peter. One ship only, the *Great Eastern*, the colossus of the seas, was capable of carrying such a burden. But the disadvantage of such a weight, which diminishes certainly by the part of the cable immersed, is chiefly felt when it has to be laid in great depths, the portion hanging down reaching a depth of 2,500 fathoms. But we are not about to describe here the process of laying a submarine cable over so long a distance. We must return to the physical side of the question.

Before it was accomplished, many persons doubted the possibility of transmitting submarine signals to great distances, as from the European continent to America, across the Atlantic. It was not so much the distance itself, as what might happen to a cable plunged to enormous depths in so eminently a conducting medium as sea-water, that frightened them. How would the wire conduct itself when the electric currents were thrown into it? Would its insulation be insufficient? Would the force of the current be sufficient to pass through it without disturbance from one end of the immense line to the other with no relay. These fears, which were at first stated but vaguely, seemed for a moment justified, when in August, 1857, after a few messages had been exchanged between the United States and Ireland, the apparatus were seen to give gradually more confused signals, and finally to cease working altogether. The cause of the interruption remained at first unrecognized.

It was necessary then to learn afresh, or rather to commence seriously the experimental and theoretical study of the transmission

of currents in an insulated and submerged line, so as to take account of obstacles, and to overcome them by appropriate means. Several physicists, among whom we may name Faraday, Wheatstone, Thomson, and Siemens, applied themselves to the task, and all contributed to the solution of this important problem.

It was recognized that a cable submerged in sea-water, is transformed, when an electric current traverses it, into a condenser analogous to the Leyden jar. The electrical charge of the line wire within acts upon the outside conductors, the metallic guard, and the sea-water, across the insulating covering composed as we have seen of gutta-percha. The induced currents which arise in this way under the influence of the current thrown into the line by the sending apparatus continue for a certain time after the current is stopped, so that a despatch of a new current is impossible till after this interval; otherwise the currents would act as if the line were traversed by a continuous flow of electricity, and signalling would become impossible. It was also proved that the conductibility of the gutta-percha is not zero, and the current is weakened by the loss which takes place across the insulating covering.

When once these causes were recognized, it became possible to counteract their effects. For galvanic electromotors, for the battery, magneto-electric induction apparatus were first substituted, as they produce currents of greater intensity, propagating themselves with greater rapidity than ordinary currents. Methods beside this have been devised for neutralizing the induced currents; one due to Whitehouse, consists in throwing alternately into the cable two currents in opposite directions, and the induced currents resulting from them are then themselves opposite, and destroy or neutralize each other. Varley interposes, between the manipulator and the line, a condenser of very large surface (40,000 square feet), which, according to M. du Montcel, works in the following way in neutralizing the induced currents: "At the moment of contact in the manipulator (which is a simple key reverser), an electric current is sent across the cable to act on the indicator, and this current is positive or negative according to which of the two keys of the manipulator has been depressed. But as soon as this key rises, a communication is established between the condenser and the earth, and

the condensed electricity can pass to the earth on both sides of the line. In this way the charge that is of opposite kind to that which furnished the first current of electricity working on the indicator, combines with the latter across the cable and neutralizes it, instantly destroying at the same time the inductive effect produced by it in the covering of the cable. In this manner the cable is restored, almost instantaneously to the neutral state, and becomes susceptible immediately of a new signal."

The system, however, which is adopted on the great transatlantic lines is this. The telegraphic apparatus is a needle one, the reason of this choice being the extreme sensibility of the galvanometers, whose needles will oscillate under the action of very feeble currents. Nevertheless, to increase still further this sensibility, and to enable the clerks of the receiving station to read the signals without hesitation, Thomson's galvanometer is employed in the following way: "In this apparatus," says M. du Montcel, "the sensitive part is a little lenticular mirror directed magnetically by a little magnetized needle, which is itself drawn back into a fixed position by a magnet; a ray of light is thrown on this little mirror, and reflected by it on a screen placed at a distance of eight feet. With this amplification, the least motion, imperceptible to the naked eye, is manifested by the displacement of the projected image, and the positions that this image successively occupy, to the right or left of a fixed datum line, indicate the dots and dashes of Morse's alphabet. All the combinations necessary for the interpretation of the messages are thus obtained, being read upon the screw in a darkened chamber."

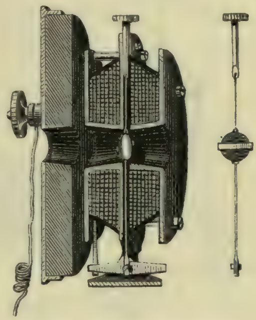


FIG. 403.—Section of Thomson's galvanometer in the telegraphic apparatus of the transatlantic cable at Brest.

Figures 403 and 404 represent the telegraphic apparatus of the French transatlantic cable, as it is set up at the station at Brest. The first is a section of Thomson's galvanometer, the second shows the general arrangement of the apparatus. In the centre of the bobbin we see a little circular mirror, which carries the magnetized needle rendered astatic by the magnet E, fixed to a vertical rod above the galvanometer. A silk thread supports the mirror, whose motions

are kept in check by a tongue fixed in the lower part; C is the commutator of the apparatus; B the manipulator with two keys, analogous to Morse's manipulator, making positive and negative currents alternately. To the negative currents correspond the deflections of the needle and mirror to the left, to the positive currents those to the right. F is a darkened chamber enclosing the scale on which are formed the images of the flame of the lamp situated behind it. The luminous beam, passing through a hole in the side of

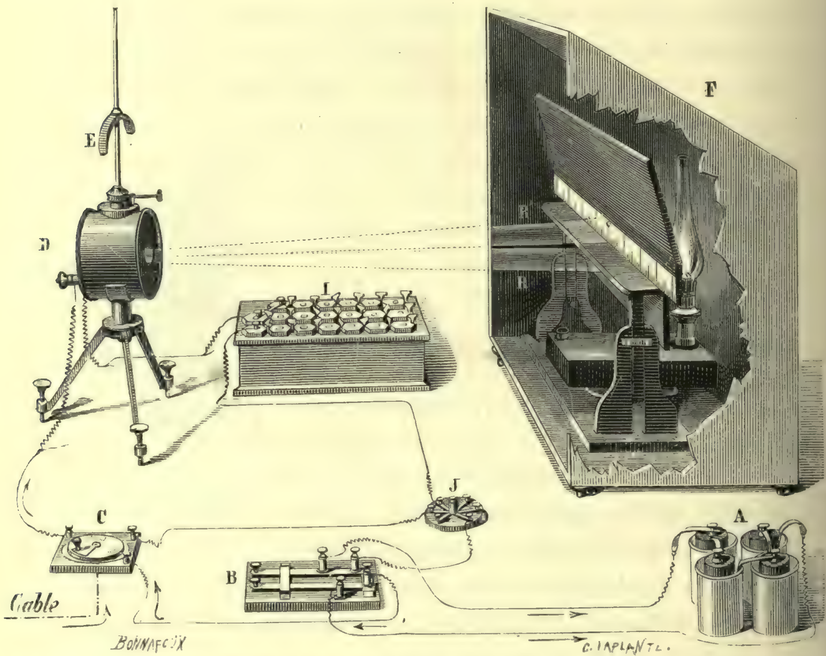


FIG. 404.—Transatlantic telegraph from Brest to St. Peter's—general view of Thomson's receiving apparatus.

the chamber, follows the path R, falls upon the mirror, and is reflected to the zero of the divided scale when the mirror is unmoved. At each passage of the current sent through the cable, the mirror oscillates to the right or left, as we have just seen, and the image oscillates horizontally on one side or the other of zero. At A is a battery of twenty Daniell's elements; at J, the communication is made with the earth.

The clerk at the station, when he has received warning that

a message is sent, puts his commutator in the position for receiving. Then he fixes his eye on the divided scale of the dark chamber, noting all the signals indicated by the successive oscillations of the luminous image, which correspond as we have said to the conventional vocabulary of Morse's system. There is nothing then left but to translate the message and write it in ordinary characters.

The syphon recorder, an instrument recently introduced by Sir William Thomson to supersede the use of the galvanometer, consists of two parts, the motor or mechanical power and the recorder for registering the signals.

The motor or mechanical part of the instrument consists of a very light and delicate insulated wire coil suspended in a very powerful magnetic field produced by permanent or electro-magnets; these, acting with great exciting force upon the suspended coil, cause it to deflect or vibrate when a current passes through it. The second or recording mechanism of the apparatus consists in imparting the motion of the receiving coil to a light capillary tube or syphon of glass suspended and adjusted to the coil by means of the torsional elasticity of a helical wire. The long leg of this syphon acts as the "marker," the short end dipping into a reservoir of ink, which is continuously ejected from the long end of the syphon by electrical agency on to a moving paper ribbon mechanically drawn forward over a metal plate electrified in an opposite way to that of the ink within the syphon. Thus a powerful difference of electrical potential is constantly maintained between the ink in the tube and the metal plate, the tendency to produce equilibrium resulting in a succession of sparks between the syphon and the metal plate, producing a fine stream of ink or a succession of minute dots upon the moving paper ribbon. Thus if the syphon remains in a neutral position, a continuous line will be drawn over the paper; but when by reason of the motion of the receiving coil the syphon is drawn either to the right or to the left, a corresponding deviation from the straight line will be indicated; thus a record is maintained on paper of the movements of the coil, without that movement being in the least degree impeded by friction or any other mechanical defects.

§ III.—The Batteries employed in Telegraphy.

The various systems of telegraphs we have described, with those we have only mentioned, may be divided, as regards their electromotive power into two classes; the first comprising the apparatus which make use of a constant battery, and the second, those whose power is derived from magneto-electric induction machines.

A whole chapter in the *Forces of Nature* was devoted to batteries; but it is well, nevertheless, to return to this subject from the exclusive point of view of their application to telegraphy.

The old batteries of Bunsen and Daniell were the first made use of, and the second is still generally employed in France, while Bunsen's battery is only used on certain American lines. In England the electric telegraph is served by trough batteries, the compartments of which are filled with sand impregnated with a solution of ammonia hydrochlorate or acidulated water, with a plate of amalgamated zinc and one of copper, in each compartment. This battery furnishes a current of little intensity, but one which is especially suitable for the systems of needle telegraphs.

Daniell's battery is easy to keep in order. It only requires a little liquid poured in from time to time to repair the losses from evaporation in the vessel containing the acidulated water and in the porous vessel containing the solution of sulphate of copper, and to see that the crystals of sulphate are always in sufficient quantity. The crystalline efflorescence, also, that is deposited on the sides must be removed from time to time, and the zinc plates replaced when the amalgamation is destroyed. The constancy of the current of this battery, which can work for nearly three months without trouble on a line so much used, and so long as that from Paris to Berlin, makes it a good electromotor. The number of Daniell's elements employed for distances of 100, 200, 400 kilometres is 30, 50, and 70.

The Marié Davy sulphate of mercury battery is also employed in France. The original arrangement of this element (Fig. 404) has been replaced by a form analogous to that of Daniell's couple with a cylinder of carbon instead of a sheet of copper. A battery of 38

Marié Davy elements working night and day over a line of 500 kilometres has furnished a current of sufficient constancy for a period of nearly four months.

The number of electro-motive apparatus invented for the service of electric telegraphy is so considerable that space would fail us to name

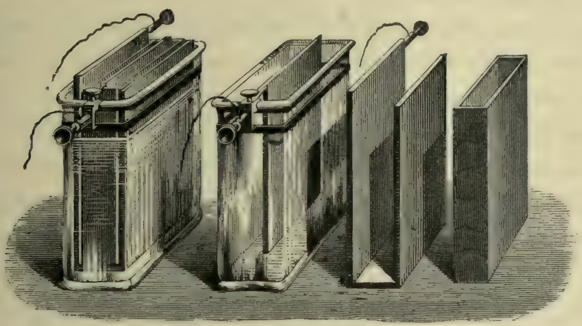


FIG. 405.—Daniell's battery employed in telegraphy.

them, much less to describe them. Many among this number are remarkable for certain particular qualities and have been used with success. It is easy however to understand that the success of their employment depends on the apparatus for which the battery is destined, according as it requires greater or less electro-motive force.

We may add, in conclusion, that a distinction must be made between the batteries for the line, which send currents to great distances, and the local batteries which have only to serve the apparatus of the station itself. These last, whose circuit is very short and which have not to furnish electricity to the line, are formed of a small number of elements whose total electro-motive force is naturally very inferior to that of the line batteries.

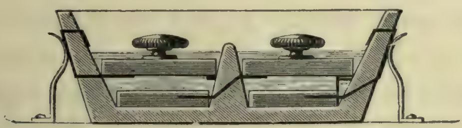


FIG. 406.—Marié Davy's sulphate of mercury battery.

§ IV.—The Alarums.

The alarums, whose office we have indicated in describing the telegraphic apparatus, may now be referred to without entering into any detail as to the mechanism which sets them in action. The systems of alarums are at least as numerous as those of telegraphic apparatus themselves. We must limit ourselves to the explanation of one or two of these systems.

The simplest and most generally adopted on French telegraphic lines is that of which Fig. 407 gives an interior view. An electro-magnet receives in its bobbin the current reaching the screw A, and thence by the handle of the hammer BM, in contact with a spring R, it goes by the button *b*, and the screw D, which communicates with the batteries, and the circuit is then closed. The hammer rod which acts as armature is attracted by the electro-magnet and the hammer strikes the bell. But the contact with the spring is by this time stopped : the current is interrupted, the hammer rod falls again upon the spring, which gives rise to a fresh current and so on, as long as the current passes through the alarum, that is to say, as we have seen in describing Bréguet's dial telegraph, as long as the commutator is on the corresponding button.

The result is a series of repeated blows, very close to one another, whence the name of *vibrating alarum*, given to the apparatus. The principle of the mechanism is due to Neef, and it was a Belgian electrician, M. Lippens, who first applied it to alarums.

When more prolonged and intense alarums are required, a catch mechanism is adapted to the system of vibrating alarum described above, which introduces into the apparatus the circuit of a local battery. Such is the alarum of M. Aubine (Fig. 408) in which a bent lever is held against the handle by a lateral tooth. When the alarum is set in action by the current of the line, the hammer being attracted by the electro-magnet, disengages the lever, which then falls on to the spring, r', and leaves r. It is easy to see then that the current from the line is broken, while that of the local battery PN is closed. The alarum is thus set in action by a more powerful current, which continues as long as the clerk warned does not return the catch-lever to its

place, which is done by means of a button on the outside terminating the lever, seen on the upper side of the box.

Electric alarums in mines have received an application of great interest with regard to the lives of the miners. The simple presence of fire damp when its proportion in the air of a mine is great enough to be dangerous, may be indicated automatically by the use of an apparatus in electric communication with a battery and an alarum. The principle on which this apparatus, invented by M. Ansell, is based, is this.

We know that if two gases of unequal density be separated by a

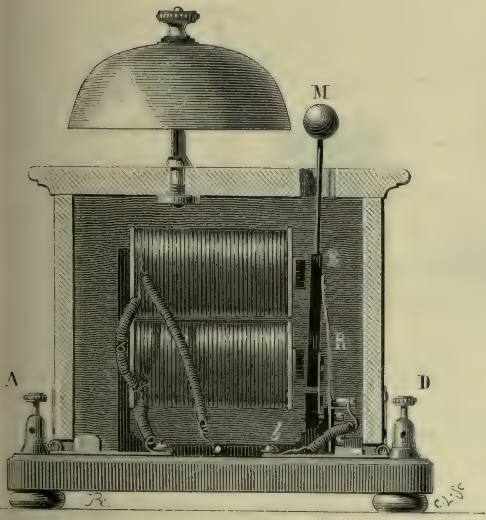


FIG. 407.—Bréguet's vibrating alarum.

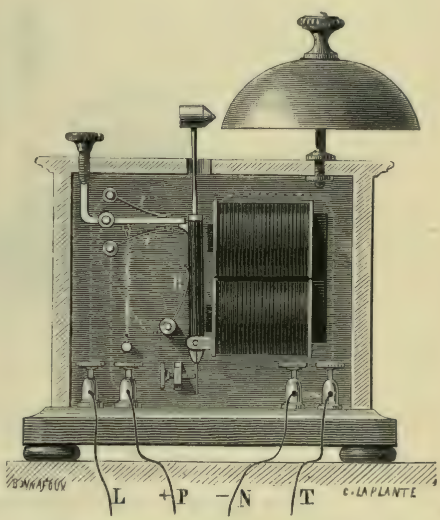


FIG. 408.—Aubine's vibrating alarum, with catch.

porous membrane, each of them will cross the membrane with a velocity peculiar to it. At the end of a certain time, there will be a mixture, but as the less dense gas crosses the porous partition in greater abundance than the other, it results that in the space occupied by the latter there will be an alteration of pressure. We will see how this phenomenon is made use of in the *fire-damp indicator* (Fig. 409).

A curved tube has one of its branches terminated in a funnel or in the form of a vessel closed by a plate of porous material *m*. The tube contains mercury whose level is the same for each branch under ordi-

nary circumstances, that is to say, when the air in the gallery is pure. But if the hydro-carbon gas is disengaged near the apparatus, it penetrates the porous plate and increases the pressure in this branch of the tube and drives back the mercury in the other branch. The mercury, in thus rising, brings the two electrodes, positive and negative *a*, *b*, of a battery into contact, by means of a metal rod *f*. The current passes, makes the alarum sound, or sends any kind of telegraphic signal either to the inside or the outside of the mine.

The same apparatus will indicate the presence of any gas that is heavier than the air, as carbonic acid or hydrosulphuric acid. It is

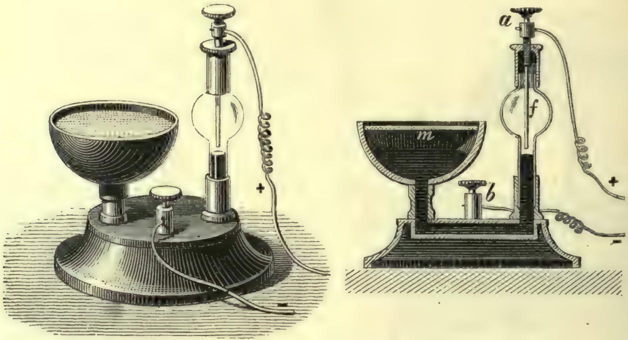


FIG. 409.—M. Ansell's fire-damp indicator.

enough for this purpose to make contact in the part of the tube which is situated below the porous plate.

Ansell's fire-damp indicator has been tried with success in several mines in England and France.

§ V.—THE LIGHTNING CONDUCTORS.

The superiority of the electric over the air telegraphs results principally from the rapidity with which public or private messages may be transmitted, whatever may be the distance within certain limits between the extreme stations. A few seconds or a few minutes at most, suffice for this docile agent to clear thousands of miles. But this is not the only reason that led to the rejection, as superannuated, of a mode of correspondence which appeared for more than forty

years a marvel of quickness; we must add the constancy, the almost absolute continuity of the working of the apparatus, on the sole condition of taking care to keep the batteries, the line, and the transmitting and receiving arrangements, in good working order. The optical telegraph of Chappe, was only of use by day, and even then but in clear weather, so that sometimes an important message arrived only in part at its destination, with this statement—*Interrupted by the fog*, or *by the night*.

Nothing like this is to be feared with the electric telegraph, which can work all the year round, night and day. But we must make one reservation, however—the transmission of electrical currents is sometimes interfered with. During storms the wires of the line are partially electrified, whence disturbances arise in messages which come from points far removed from this accidental phenomenon. The aurora borealis produces similar effects and irregularities, for which there is not yet any certain cure. These disturbances may be strong enough to cause damage either to the line or to the stations and their apparatus. In storms of considerable violence, the lightning may break the poles or the porcelain insulators; the magnets and the compass needles may become demagnetized—which will not astonish the reader if he is acquainted with the electro-magnetic phenomena we have described in the *Forces of Nature*. The armatures and the bars of soft iron forming the electro-magnets may, on the contrary, receive, under these circumstances, a permanent magnetization which will render them useless.

There is no remedy for this except a careful surveillance of the line and the apparatus at the stations, and the repeated testing of their proper working, especially in times of storm, or when auroras make their appearance. In cases of damage the broken parts must be replaced; but as these things are now foreseen, well organised lines keep the most indispensable parts for renewal at all the most important stations, and in the result the interruption is not for long.

There is, however, a danger which may be foreseen and effectually guarded against, and it is one which threatens the security and the life of the clerks at the stations. In the first days of electric telegraphy, strong sparks sometimes passed between the metallic parts of the apparatus; the discharge broke them, scattered them to

a distance, and wounded or killed the persons who might be in the path of the electric fluid. Each station, has, in consequence, been provided with a very simple little apparatus, for the purpose of drawing off the electricity of the storm to the ground, and of saving the instruments and the clerks at the same time. These lightning-conductors are various in principle and form. We will describe a few of those most in use.

Bréguet's lightning-conductor, represented in Fig. 410, is of great simplicity. It consists essentially of two toothed metallic plates whose teeth are opposite each other; of a tube inclosing a very fine iron wire, connecting electrically the screws *a* and *b*; and of

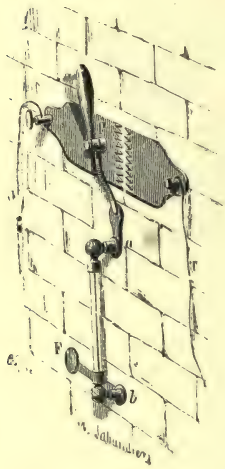


FIG. 410.—Bréguet's lightning-conductor.

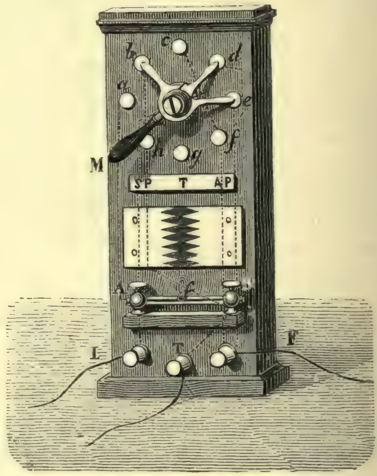


FIG. 411.—Lightning-conductor on the French telegraphic lines.

a commutator, P. When the handle of this last occupies the position shown in the figure, the current from the line passes from L to F, and thence into the apparatus of the station. The electricity of the battery is not of sufficient tension to cross by the points of the plates, and continues its ordinary course, but the atmospheric electricity, on the contrary, is able to do so, and passes from the points by the wire T to the ground. If the storm is violent, this way of escape may be insufficient, and the electricity may pass through the wire, and heat and even fuse it. But in the last event, the communication with

the station is interrupted by this very fusion of the wire, and the electricity of the storm passes to the earth. If the storm has been foreseen, the clerk can put the commutator in connection with the earth wire, and all communication with the station is then cut off.

Fig. 411 represents another arrangement of the lightning-conductor which is also based on the power of points, and on the different behaviour of electricity according as it arises from galvanic currents or is due to an atmospheric disturbance. The commutator is provided with three branches. When the middle one is on the button *d*, as shown in the figure, the current from the line goes directly to the station, its course being easily seen by following the dotted lines which mark the electrical connections of the various parts of the apparatus. From the end L of the line wire, the current passes through the commutator and thence by F to the station, without passing through the wire *f* at all. In the event of a storm, the middle branch is placed on the button *b*, and then the current crosses the pointed plates and the wire before reaching the station. And further, if the storm be violent, the commutator is put opposite the letter T, with its middle branch on the button *c*. Then all the currents pass directly to the earth without any communication whatever with the station, which is thus preserved from all danger.

Bianchi's lightning-conductor is also founded on the power of points. When the electricity of a storm comes from the line, it passes away by a series of points arranged upon a glass bowl all round a metallic sphere, which, by a metal ring is in permanent communication with the earth. If the glass bowl is exhausted the passage is quicker, but this precaution is not absolutely necessary.

The lightning-conductors represented in Figs. 412 and 413 are not based on the power of points, but simply on the inequality of electrical tension between the regular line currents and those of atmospheric or storm cloud electricity. While the first is stopped by an insulating sheet and enters the apparatus, the other crosses to the large conductor offered to it, in spite of the interposition of the insulating body. It can thus easily pass on to the earth without causing any disturbance or damage in the station.

Siemens's and Halske's lightning-conductor (Fig. 412) is composed of a plate of cast iron in communication with the ground; upon this, and as near as possible to it without being in actual metallic

contact, rest two smaller plates, A, B, connected on one side with the line wires, L, L_2, and on the other with the apparatus F, F_2. The galvanic currents have not sufficient intensity to overcome the resistance arising from the distance of the conductors from the plate in connection with the earth, but in the case of a storm, the atmospheric electricity takes this latter path and the instruments are preserved.

The lightning-conductor on the Belgian lines (Fig. 413) also consists of metallic plates, *pp*, *df*, separated by an insulating sheet of thin paper. The line wires of the two neighbouring stations on the right and left terminate in L and L′, and those of the apparatus of the station itself in F and F′; T communicates with the button *b* and with the earth. Four holes, 1, 2, 3, 4, in the socket of wood which carries the plates are made to receive a metallic plug, *c*, which puts the

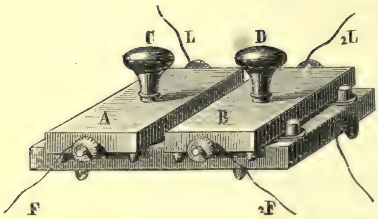


FIG. 412.—Siemens's and Halske's lightning-conductor.

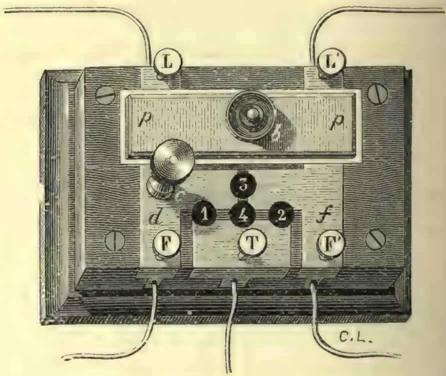


FIG. 413.—Lightning-conductor on the Belgian lines.

various parts of the lightning-conductor in connection with each other. In ordinary times the plug is in the position marked in the figure, and then the neighbouring stations can communicate with the apparatus in this one, and the correspondence on both sides is free. If a storm appears on the right, the plug is placed in the hole No. 2, and the atmospheric electricity passes to the earth by the plate and wire T. If the disturbance occurs on the left, the plug is placed in hole No. 1; and lastly, it is placed in No. 4, if both sides are threatened at the same time. The hole No. 3, serves to establish direct communication between the two lines, so that the apparatus is at the same time a commutator as well as a lightning-conductor.

§ VI.—Duplex Telegraphy.

Very early in the development of the telegraph it became known that a wire would transmit more than one current at the same instant of time, and that when the currents were passed into the wire in the same direction, the effect of the duplication of the currents upon the directive force of the needle at the distant station was greatly increased, and when the currents were in opposite directions the movement of the needle was almost imperceptible, and that if the currents were accurately balanced the needle would remain stationary. The application of these known facts to the indicating of distinct signals constitutes Duplex Telegraphy. In carrying out this system of transmission it is necessary that the coils of the instruments at the sending and transmitting station shall be so arranged that whenever the transmitting station sends a current into the line, although it may be indicated at the distant station, it is neutralized upon the coil of the sending instrument, and no signals are shown; but the instrument remains free to receive signals from the distant station. This neutralization or balance is obtained by winding the coils of the instruments with two parallel wires, after the manner of a differential galvanometer.

Therefore when the distant station sends a current, it either increases or reduces the effect of the local current, but in passing through the coil of the transmitting instrument it is equally divided, neutralizing its effect upon the needle of that instrument, but at the distant receiving instrument the current passes through both coils in the same direction, and therefore exercises a directive force upon the needle, and indicates a signal. The Duplex system is capable of increasing the transmitting capacity of a wire, two, three, or four-fold as may be required. The system is now extensively employed both upon the Postal Telegraph lines in Great Britain and on many telegraph lines in the United States and Europe.

§ VII.—The Universal Telegraphic Network.

It is scarcely necessary, perhaps, to insist on the importance of electric telegraphy in matters of private, public, and international interest. This application of one of the branches of physics, which has made so great progress during the last century, is so brilliant a conquest of human ingenuity over time and space, that no one can doubt the enormous range of its usefulness. Confined at first to public and governmental correspondence, or diplomatic despatches, it has received all its development since it has been required for serving private interests. The use of the telegraph has been since then prodigiously extended, and it still daily increases, in proportion as the number of stations is augmented. Thus in France alone, twenty years ago, seventeen telegraphic stations sent off annually scarcely 9,000 messages, while now, 3,500 stations send more than six millions.

Telegraphic communication not only serves for the purposes of families or friends, but still more for purposes of business, commerce, arts, and speculations in shares. So far for private interests. In diplomacy, war, public works, administration, politics, and police, it is continually made use of. In a higher and more serene domain, that of science, it renders the greatest service, by furnishing astronomers with the means of determining the longitude with precision, of signalling to all the observatories the discovery of new stars, comets and planets, and thus gaining weeks in verifying and registering the discoveries. In meteorology the telegraph announces coming storms, and the rising of water, sends warnings to seaports of squalls, and so supplies navigation with precious information such as has already saved ships and cargoes from disaster.

This enumeration of the services rendered by telegraphy is very incomplete. But the best way to demonstrate its importance is to transcribe here a few figures indicating the actual state of the network of air and submarine lines which are now at work all over the surface of the earth.

The length of lines over the whole earth is very nearly 400,000 miles, that is, sixteen times the earth's circumference. In this total

the submarine telegraphs are distributed among 231 cables of very unequal lengths.

In Europe the air lines measure nearly 200,000 miles, among which Great Britain is represented by 58,000 miles, or one mile of telegraph to each square mile of area, and France by 29,000 miles, or one mile of telegraph to seven square miles.

The number of messages sent has increased in an enormous proportion. To give an idea of the greatness of the correspondence in industrial countries, we may mention that in England, in the year 1870, shortly after the acquisition of the telegraphs by the State, 10,200,000 messages were sent, or 203,600 per week. M. W. Huber, to whom we owe these statistical details, tells us that on the 18th of July, 1870, the day on which the declaration of war between France and Prussia was known in London, 20,592 messages passed in the central station alone. The telegraph to India sent in 1871 33,000 messages; and in spite of the high price of correspondence by the transatlantic cables, 240,000 messages crossed the ocean in a single year. These numbers fall far short of the total number of messages sent in 1875, the annual increase being on an average about 20 per cent. on the preceding year's traffic.

These statistics are sufficient to give us an idea of the impetus given to rapid correspondence in various parts of the globe, but they may be advantageously supplemented by a special reference to the trans-oceanic lines. Europe is in direct communication with the North American continent by seven cables, five of which start from Valentia in Ireland, and the other from Brest, and end in Trinity Bay in the Island of Newfoundland, or at St. Peter Miquelon, and go on from thence to the territory of the United States. Two of these cables, those laid in 1865 and 1866, are at this time (1876) interrupted. South America is also connected with Europe by a submarine line passing by Madeira and the Cape de Verde Isles, and ending at Buenos Ayres, upon the east coast. From thence land wires extend to Valparaiso on the west coast, and by submarine cable up to Ecuador.

At the present moment again, India is in telegraphic communication with Europe by three lines; one runs along the Red Sea, and then in the Mediterranean ramifies into several branches which go to Sicily, Italy, France, and on to England, to the coast of Portugal

and thence on to the most south-easterly point of Great Britain, beneath part of the Atlantic; the other line ramifies in the same way, starting from the Gulf of Persia, by several air lines which go to Russia, Germany, and Syria, and China and Japan are connected by Northern Russia. Lastly, Australia and New Zealand itself is in communication with the Indian lines, so that a message sent from Sydney or Auckland, arrives directly at London, New York or Boston, and thence by the telegraph crossing the American continent to San Francisco, on the shores of the Pacific Ocean; 270° of longitude, or more than 30,000 kilometres, actual distance, are traversed by electric signals under special conditions in less than one hour. In practice, however, a much longer period of time is found necessary. The following fact will suffice to give an idea of the rapidity of electric correspondence:—

At a banquet given upon the opening of the telegraph between Australia and London, and at which those interested in the undertaking were present, and which was held at the same time in London and Adelaide, a telegraphing instrument was placed behind the President's chair in London. At the opening of the banquet, a congratulatory message was sent to Australia; before the end of the banquet, the reply with a concluding hurrah! returned from Adelaide.

It is clear from what has been stated, that a gap is still to be filled before the entire circumference of the globe is inclosed in the network. America and Asia do not as yet communicate directly with each other. But four lines, two of which are entirely submarine, have been projected, and the Pacific Ocean will doubtless be soon traversed by electric currents, as the Atlantic has already been for eight years. In course of time, messages will arrive in London and Paris from all the remotest parts of the globe, and we shall read in the papers in the evening an account of the principal events which have happened during the day (and night too) in all five parts of the world. It may be left to each to conjecture what will be the influence in the future of this continuous communication on political, commercial, and industrial relations—or in one word, on our whole progressive civilisation.

CHAPTER VI.

ELECTRIC HOROLOGY.

§ I.—Electric Regulators.

The rapidity with which electric currents are propagated, the all but instantaneous manner in which they produce motions in two instruments suitably arranged and connected by a conducting wire, have suggested the idea of applying to chronometers the principle of the electric telegraph. The synchronism of its motion enables us, in fact, to make the hands of any number of dials fixed at points at a greater or less distance from each other, move in perfect accordance, as, for example, those at the different stations on a railway line. It is simply necessary to put all these dials in electric communication with a single regulator. This is one problem which has, in fact, been solved, and the arrangements invented for the purpose have been in use a long time, both on railways and in great towns whose public clocks are thus regulated.

But it is a distinct problem, which, however, like the former, has been solved, to apply electricity to the motion of the regulating clock itself. It is for instruments of this latter kind that the name *electric clocks* is generally kept. Those arrangements which are simply intended to transmit to clocks at a distance the motion of an ordinary timekeeper, have received the name of *electric regulators.*

Lastly, electricity has been required to bring into union a certain number of clocks, each having its separate works and powers, so as to establish the regular agreement of their independent rates.

In these various applications, as in telegraphy, there are many systems; we must therefore be content with describing one or two of the types which have been sanctioned by experience, and which will

explain to us all the ingredients requisite for this new application of electro-magnetism. We will describe first the electric regulators.

There are two distinct parts in an apparatus of this sort, as indeed there are in every telegraphic apparatus. There is first the mechanism connected with the regulating clock for transmitting and interrupting periodically, and at equal intervals, the current from a battery, or some other electromotor. This current communicates the motion to the receiving apparatus, that is, to the mechanism for moving the hand on each dial. This is the *indicator.*

Take for example Garnier's regulator.

The regulating clock is an ordinary one, and the following is the

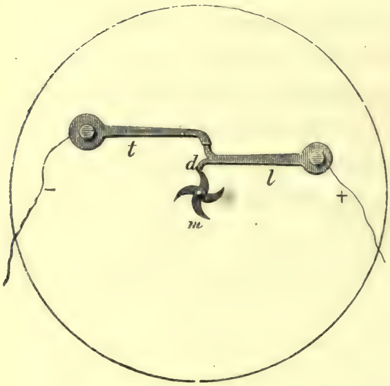


FIG. 414.—Garnier's electric regulator: transmitting apparatus.

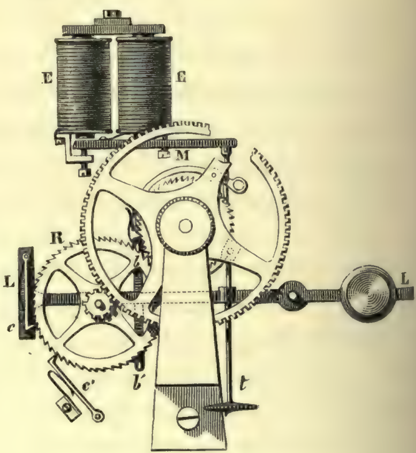


FIG. 415.—Indicator of Garnier's electric regulator.

simple way by which, when in motion, it successively transmits and stops the current in the circuit. The dial-wheel of the clock carries on its axis a wheel with four cam-shaped teeth. The rotation of the wheel first raises the hook *d* of the lever *l*, and then lets it fall. In the first case, that represented in Fig. 414, the two poles + and − of the battery are in communication by the contact of the two metallic levers *t* and *l*; the circuit is closed and the current passes. In the interval of the passage from one tooth to another, the lever *l* falls, contact ceases, the circuit is opened, and the current is interrupted. The contacts of the two pieces are made of gold, or of an alloy of gold and platinum, in order to avoid oxidization, which would stop the

passage of the electricity. The *indicator* of Garnier's regulator is represented, in its essential features, in Fig. 415. An electro-magnet attracts or repels (according as the current from the regulating clock passes or is interrupted) an armature, M, which in turn raises the lever LL by the rod *t*. One of the ends of this lever carries a catch, *c*, which as it rises draws on by one tooth the ratchet-wheel R. Two stops, *b b′*, prevent the wheel, on the other hand, from turning through more than one tooth, and from going back. When the current is interrupted, the armature falls back on the screw which one of the bobbins carries on its lower side, the lever LL is lowered, and the catch *c* comes against the next tooth, which it stops until the passage of the current energises the electro-magnet again.

From the ratchet-wheel the motion is conveyed by properly-arranged gear to the minute wheels which turn the hands on the dial. The

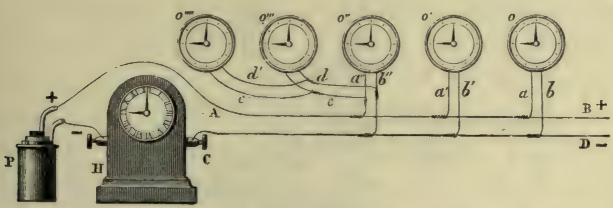


FIG. 416.—Telegraphic connection of the regulating clock with the indicators.

regulating clock and the indicator being now regulated to agreement once for all, this agreement continues as long as the battery works with sufficient strength for the attraction of the armature.

We must now see how a series of indicators is united to the regulating clock, and how they are all able to go under the original influence of the first, without an interruption of one of them interfering with the others.

Two large metal wires, AB, CD, leave the battery P after having passed through the regulating clock H, as we have already shown. From each of the wires run other pairs of wires at *ab*, *a′b′*, &c., of smaller diameter, communicating with each indicator, *o*, *o′*, *o″*, &c. By this means the principal circuit is divided into as many derived circuits as there are dials, and communicates the movement to each of these independently, or we can connect the wires *cd*, *c′d′* with those of one of the indicators, as *o″″* and *o‴* with *o″*.

It appears that in Garnier's regulator the antagonistic force is that of gravity, so that these apparatus can only work on one condition, and that is that they should be placed in a vertical position. The advantage is the constancy and invariability of this force, which is not a property of the elasticity of springs (see Froment's system). The regulating clock was at first an ordinary one with a ratchet-wheel whose teeth came against a fixed spring at each second. This spring was simply a thin sheet of gold in communication with one of the poles of the battery, while the wheel itself was connected electrically

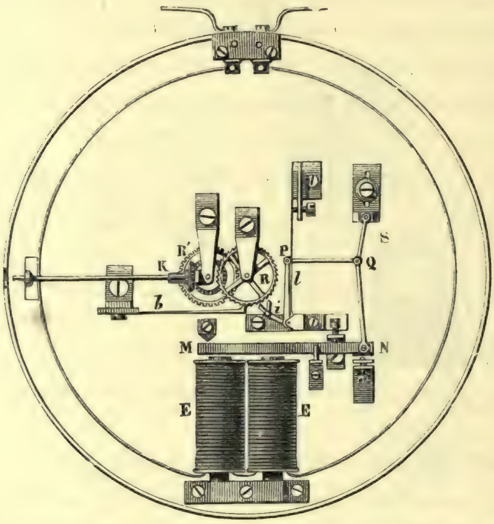


FIG. 417.—Froment's electric regulator : the indicator.

with the other pole. There was in this case in each second, first the passage, and then the interruption of the current afterwards. M. Froment substituted an electric regulating clock for the ordinary one.

In the indicator, of which Fig. 417 represents the arrangement, the armature MN has at the end nearest N a continuation of copper, to which is articulated a system of two levers, SPQN, whose branches, SQ, QN, tend to straighten themselves when the armature is attracted by the passage of the current. The rod PQ then acts on the bent lever Pi, and the catch i pushes on the ratchet-wheel R by one tooth.

When the current is interrupted, the armature is drawn back by the spring *l*, the branches SQN bend again, and the catch leaves the ratchet-wheel free. The catch *b* prevents the return.

The motion is communicated to the minute wheel worked by the wheel K′, and a bevel wheel arrangement carries it on to the hands by means of the rod K.

The originality of Froment's regulator lies chiefly in the employment of the distributer SPQN. This mechanical contrivance is destined to proportion the resistance to the attractive force of the electro-magnet in the armature. This attraction is greatest when the distance is least, that is, at the moment of contact, so that it is just at the moment when the motion is about to cease that the velocity of the parts attains its greatest value, which is a great disadvantage to the mechanism. But by the use of this distributer, the resistance increases in the same proportion as the attraction, so that the attractive force of the electro-magnet remains constant.

The electric regulators of Bain, Ritchie, Bréguet, Robert Houdin, and Nollet are as deserving of description as the above, but we must limit ourselves to the preceding systems, mentioning only those applications that have been made with success. At Paris, Lyons, Marseilles, Brussels, Ghent, and Leipzig, the regulators of these systems have been worked, and are still being worked, and show the time regularly and concordantly in the different parts of these towns.

Illuminated clocks are nothing but gas reflectors, within which the regulators are placed, and which have time dials on one or two of their faces. Messrs. Nollet at Ghent, Detouche at Paris, and Bréguet at Lyons, have constructed apparatus of this kind. Fig. 418 represents the outside and inside of the twenty-four illuminated clocks fixed in Lyons by M. Bréguet. The electro-magnets, E E′, are seen to be double; they are so placed that their contrary poles face each other, so that the armature M, which is magnetized, is at the same time attracted by one and repelled by the other, or inversely, according as the current passes in one or the other of the electro-magnets. The rod T carried by it acts by means of a fork, furnished with a peg, on two catches *i*, *i*′, which play the part of an escapement anchor and move the teeth of a ratchet-wheel, to the axis of which the minute-hand is attached.

In order that these electric regulators, whatever system is adopted, should work with constancy and regularity, it is obvious that they require constant attention and care. The proper state of the various pieces, that of the regulating clock, and above all the maintenance of the battery, are conditions of the first necessity. This is so evident that we need not insist on it. But since, after all, one of these conditions may fail, it is plain that the very thing which constitutes the superiority of this arrangement over ordinary clocks, namely, the

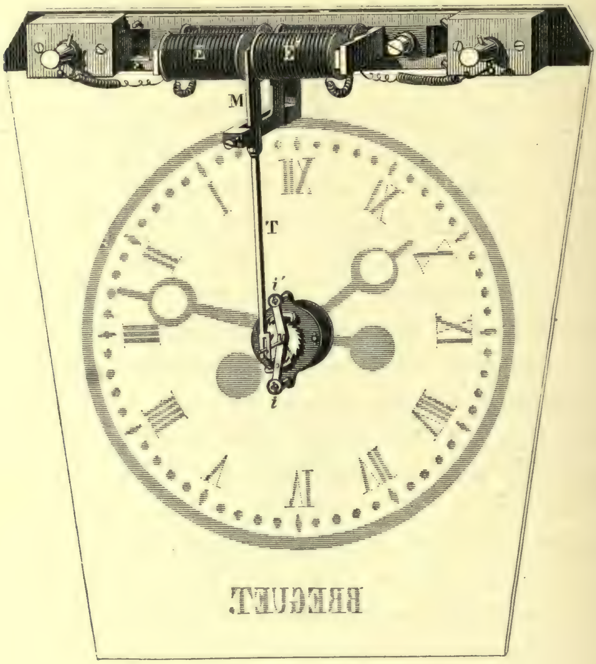


FIG. 418.—Bréguet's illuminated clock.

working together of all the timepieces of the town or railway, would be a great disadvantage in case of an interruption. It is advisable, therefore, not only that the regulators should be independent, as we have seen to be the case in Garnier's system, but the motion should not depend on a single regulating clock. By dividing the town into departments, each of which possesses a regulator, such a great inconvenience as this is diminished in like proportion.

§ II.—Electric Clocks properly so called.

We have seen in the book devoted to gravitation that the driving power of clocks is derived either from a weight or from a spring, and that the pendulum serves to regulate the motion communicated to the wheels by this force. The regularity of their motion depends on that of the oscillations of the pendulum, whose amplitudes should remain as far as possible invariable. The motion of the pendulum is moreover kept up by the action of the escapement.

The problem sought to be solved by the inventors of electric clocks is to give to the pendulum directly, and without the employment of a motor, or of ordinary wheels, an impulse derived from electricity, which shall keep up and regulate its motion. The following are some examples of electric pendulums in which this condition is realized.

That represented in Fig. 419 is one of the oldest; it is due to an ingenious and experienced clockmaker of Beauvais, M. Vérité.

The pendulum B, hung by a spring or isochronous support, carries a rigid crossbar, AD, with two pegs, which move freely inside two metallic bells, C and C′. These latter are suspended by very fine silver threads armed with counterpoises, p and p, to a horizontal lever, whose two branches are insulated in the middle by a piece of ivory. Two electro-magnets, E and E′, have their poles placed opposite two armatures of soft iron carried by the lever, and each is connected metallically with the corresponding branch of the lever and also with one of the poles of the battery. The other pole communicates by a wire with the suspending spring of the pendulum.

When the pendulum at rest is vertical, the pegs of the crossbar AD are not in contact with either of the bells. But contact takes place with one of them, say that to the right, when the pendulum is started towards the right. By this contact the circuit is closed and energizes the electro-magnet E′, which attracts the right-hand branch of the lever. The bell C′ goes down, and by its weight acts on the peg and gives the pendulum an impulse in a retrograde direction. Through the motion thus impressed, the contact of the peg with C′ ceases, and the current is broken. But the pendulum, in moving to

the left, brings the left hand peg into contact with C; the contact on the other side is now closed; the electro-magnet E acts on the left-hand branch, and the bell C, in turn, falls on the side A of the crossbar, and so on indefinitely.

M. Froment's electric clock, Fig. 420, owes its motion to the periodical action of a little weight, *p*, which comes into contact with a lateral screw every time the circuit is closed. The regulator is arranged and works in this way:—The pendulum B, suspended by an

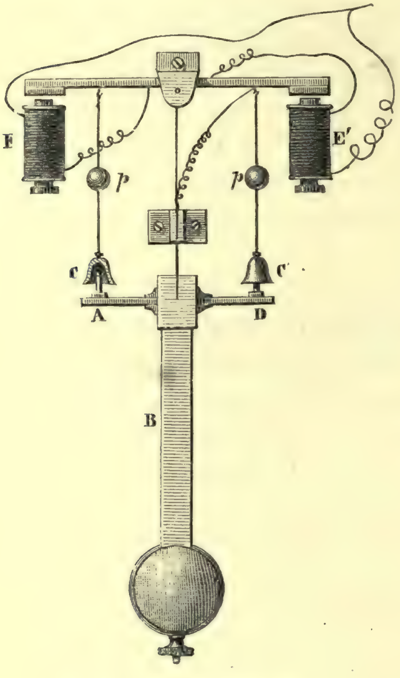


Fig. 419.—Vérité's electric clock.

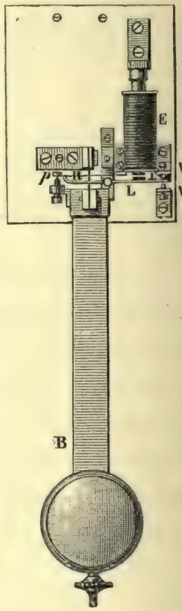


Fig. 420.—Froment's electric clock.

isochronous spring, is in direct communication with the positive pole of the battery. The other pole is connected with the wire of the electro-magnet E, which communicates with a spring band, at the end of which is soldered the weight *p*. The branch R of a lever RL sustains this band and weight when the circuit is open, the other branch, L, carries an armature which is attracted by the electro-magnet every time the circuit is closed and the current passes. Now the opening and closing of the circuit are produced at each successive oscillation

of the pendulum. During that part of the oscillation which takes place to the left, the screw touches the weight *p*, the circuit is closed, the armature attracted, and the branch R of the lever ceases to sustain the band and weight, which then acts on the screw, and in consequence on the pendulum, so as to give it a retrograde impulse. Then the contact ceases, the circuit is opened, the armature takes its original position, and the weight ceases to act. Two screws, V and V′, limit, on the other hand, the course of the branch L of the lever. Hence it is the action of a constant weight, which at each oscillation maintains the motions of the pendulum.

Robert Houdin's electric clock is represented in Fig. 421. The suspending spring of the pendulum P is in communication at *o′* with the positive pole of the battery. It is provided with two curved arms, B and B′, which alternately come into contact with two spring bands, and so close the circuit, first with the electro-magnet E, and then with the electro-magnet E′. Suppose the oscillation of the pendulum begins on the right side of the figure, and the contact is then made by the arm B. The current following the wires in the direction marked by the arrows passes by E′; the left branch of the armature AA′, being attracted, raises the spring which acts by means of the rods *t′*, *l*, and a catch on a ratchet-wheel, and makes it advance one tooth. The same motion raises the little mass *l*, and draws up the catch *c′* below the spring, which is thus stopped, while the right-hand spring is disengaged from the catch *c*, and is enabled to act by its weight during the retrograde motion of the pendulum. Then the contact ceases, the current is interrupted, the left hand armature ceases to be attracted, the rod *t′* is lowered, and drives the upper corresponding catch over the next tooth of the ratchet-wheel.

The motion of the bob towards the left brings B′ into contact with the left-hand spring. The current circulates through the electro-magnet E′, the armature on the right is attracted, and the same motions which we have just described take place on the opposite side, so that it is now the left-hand spring which, when disengaged, acts by its elasticity and its weight on the arm B′ of the pendulum, and the catch *r′* is drawn in its turn over one tooth of the ratchet-wheel. Two counterpoises, *e e′*, which can be set at different distances on the spring bands, are the means of regulating the action of these springs, and, consequently, the motion of the pendulum itself.

We will describe one more very ingenious electric clock (Fig. 422), which, like the preceding, may be made, if desired, to go alone, or to serve as regulating clock for a series of dials electrically connected with it. It is due to a clockmaker of Neufchâtel, M. Hipp.

We must first describe the mechanism of the regulator. It is composed of minute wheel work, to which the motion is communicated by the oscillations of a pendulum. So long as the oscillations of the pendulum have a sufficient amplitude, the electricity is not

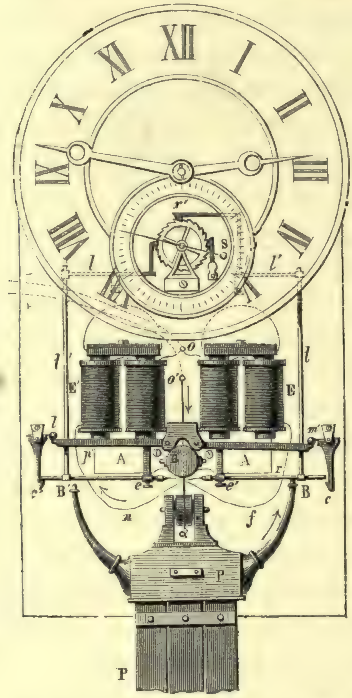


FIG. 421.—Robert Houdin's electric clock.

called into play. If, on the contrary, the amplitude diminishes the current acts through the attraction of the poles of an electro-magnet, and an impulse given to the pendulum impresses on it the required motion, and keeps up the regularity of its oscillation in the following way.

The electro-magnet E, Fig. 423, is firmly fixed below the pendulum, so that the line of its poles is a little on one side of the rod in its vertical position. The pendulum carries an armature

at A, which at each oscillation passes at a very short distance from the poles (about twice the thickness of a piece of paper). Below its end is fixed a tongue, P, or little steel plate, which is jointed to a horizontal axis, about which it can move freely, and is terminated by a knife edge.

This tongue goes to and fro with each oscillation of the pendulum, and slides, without pressing, on a raised bar with two notches, called the detainer, and which is supported by a spring, and communicating by one of its extremities with the negative pole of the battery. When the oscillation of the pendulum is of sufficient amplitude, the tongue passes over the detainer, but if the motion is relaxed it stops in the position marked in the figure, and at the commencement of the returning oscillation comes to a stop against one of the notches; if the detainer could not then be lowered, the pendulum would stop, but the spring which carries the detainer yields, contact is made with the termination of the other wire of the battery, and the circuit is closed. The electro-magnet being energized, the armature of the pendulum is attracted, and this attraction giving the necessary impulse for the maintenance of the pendulum's motion at the following oscillation, everything is re-established in the original order, and it is only when a new impulse becomes necessary that the electricity is called into play.

The time which elapses between two successive impulses depends on the force of the pile. It has been called by M. Hipp the duration of impulse. It may be several minutes or only a few seconds. With one Leclanché element, a regulator of this system will go for several months.

We now come to the mechanism of distribution, which communicates the time of this regulating clock to any number of indicators connected electrically with it and with the battery.

The ratchet-wheel R, having 60 teeth, and which at each oscillation of the pendulum moves one second, carries on its axis a metal ray or branch *b*, which makes one turn per minute, like the ratchet-wheel, and which touches at any given moment one, two, or more of the tongues attached at C C to the line-wires—one current per minute is thus thrown into each indicator, whose mechanism works under its influence. Since this mechanism, which we cannot describe here, requires a periodic change in the direction of the current, the regulator

has a reverser, the details of which are represented on the right of the figure—a wheel R′, moved by a pin on the ratchet-wheel, carries on its radii some pegs which press on the branches of a forked lever *f*, and make

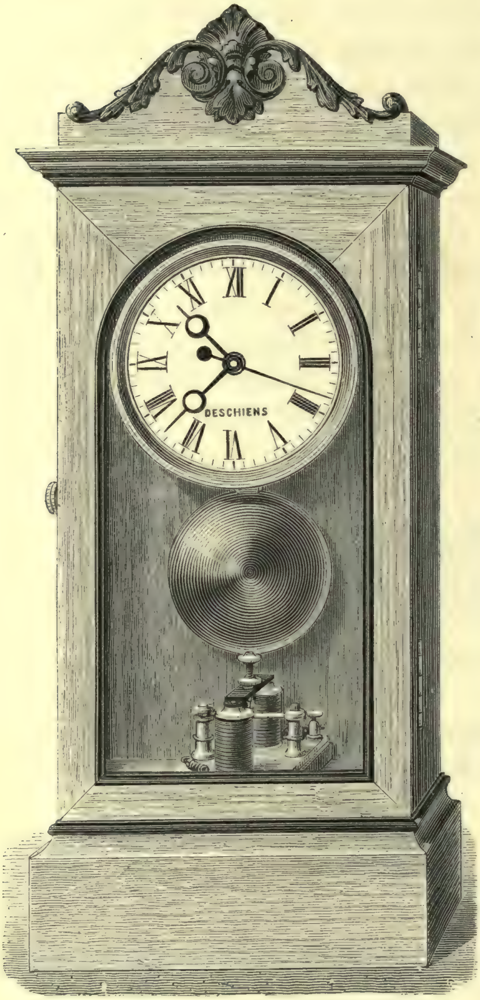


Fig. 422.—Hipp's electric clock: outside view.

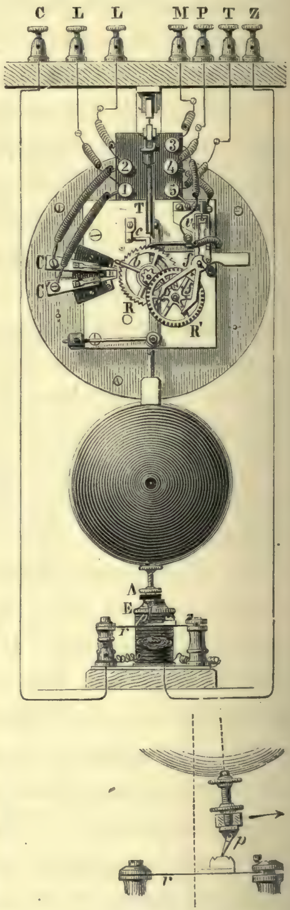


Fig. 423.—Details of the regulating and distributing mechanism.

it oscillate about its point of support. Two spring bands, fixed to the other branch of the lever, oscillate in this way about a mean position, and so one after the other establish contact first with the positive and then with the negative pole of the battery.

§ III.—Electric Time Signals.

A very important application of electricity is that of the accurate determination of longitude between British and the more important Continental observatories, and the indication at distant stations of Greenwich mean time. The spread of railways throughout the length and breadth of the United Kingdom necessitates the punctual departure of trains according to published time-tables. In Great Britain, Greenwich mean time is employed at all stations from Penzance in Cornwall to Lerwick in Shetland. In Ireland Dublin time is taken, the constant difference between Dublin time and Greenwich time being allowed. The indication of true time by an audible signal, by means of the isochronism of controlled electric clocks was first practically carried out at Edinburgh, by Professor Piazzi Smyth, the Astronomer-Royal for Scotland, between the Royal Observatory, Calton Hill, and the Castle. The daily discharge of the gun at 1 P.M. from the castle ramparts in this instance is effected by means of two clocks connected by a wire, the one at the observatory, the other upon the castle ramparts adjacent to the gun, and their isochronous action is ensured by magneto-electric controlled pendulums. At the precise moment of time the castle clock liberates a weighted trigger which mechanically effects the discharge of the gun. There is no city in the world in which time is generally so accurately kept and observed as Edinburgh, and the chronometrical arrangements of the Royal Scottish Observatory are fully appreciated. The indication of true time at a distant station—of an audible signal by the direct action of an electric spark—was first carried out by Mr. Nath. J. Holmes, at the Meeting of the British Association at Newcastle-upon-Tyne, in 1863. In that year a gun was discharged from the ramparts of the old Roman Tower, the ignition being effected by the direct action of a magneto-electric spark transmitted through the telegraph wire between Edinburgh and Newcastle. One end of the wire was connected with a magneto machine, and the circuit automatically closed at the precise interval of time by the Observatory clock, while the Newcastle end of the wire was in connection with a detonating fuse inserted into the touch-hole of the

gun. Thus Greenwich mean time was daily announced at Newcastle from Edinburgh during the Meeting of the Association, by the discharge of a gun at 1 P.M., electrically fired from the Observatory 125 miles distant. This Newcastle electric time-gun experiment by Holmes is historically of interest as having formed the initiatory experiment which resulted in the establishment of the electric-torpedo system of defence, so successfully employed by the Confederate States in their naval operations during the continuance of the American civil war raging at that date; a system which has been the basis of the present more highly developed torpedo defence, in use by the various European powers. By a modification in the arrangements for the transmission of the spark, Holmes afterwards successfully established a chain of electric time-gun signals, fired daily at 1 P.M., in connection with the Edinburgh Royal Observatory—south, at Newcastle, North Shields, and Sunderland, and west, at Glasgow, where three guns were planted, on the high ground of port Dundas for the city, at the Exchange for the merchants, and at the Broomielaw for the shipping, and a fourth gun at the Albert Quay, Greenock, for the docks and vessels lying at the tail of the Bank. The Astronomer-Royal for Scotland, Professor Piazzi Smyth, in 1863, had therefore eight time-gun signals daily discharged at 1 P.M. from the Observatory, Edinburgh. Seven of these guns are now historical, the castle gun alone being daily discharged in connection with the Edinburgh Royal Observatory.

The acquisition of the telegraph wires by the Post Office has introduced a modified system of electric time-signal currents disseminated over the kingdom from the Greenwich Royal Observatory.

These electric Greenwich time-currents may be classified into two groups. First, the metropolitan, and second, the provincial currents. By the first group Greenwich time is given by special wires every hour to London; by the second group, Greenwich time is given to the country by means of the telegraph lines twice a day, at 10 A.M. and at 1 P.M. The necessary electrical contacts and currents are automatically controlled and distributed by means of an apparatus termed a "chronopher." The indication of true time is variously registered; at times it is by the dropping of a time-ball placed upon a roof or tower in a conspicuous situation, or by the beat of an ordinary galvanometer needle, the stroke of a bell, or, as already noticed, by the discharge of a powerful cannon. This last method is the most

valuable and practical mode of communicating time audibly over an extended area, due allowance being made for the rate at which sound travels, and the position of the observer as regards direct distance from the gun. Sound travels at the rate of a little under a quarter of a mile in a second. From the rapidity of the motion of light, the flash of the Edinburgh time gun can be seen from the shipping in the Firth of Forth, and true time indicated long before the report of the discharge of the gun has reached the ear of the observer.

The Greenwich hourly time-currents over London are distributed chiefly by wires in connection with the lines of the South-Eastern Railway Company, the elaborate and delicate adjustments for which are entrusted to Mr. Charles V. Walker, F.R.S., to whom practically the vast metropolis of London has to look for the daily accuracy of her chronometrical arrangements and time measurements. Electric time-signal systems are now very extensively employed in the United States of America, the continent of Europe, and also in some of our Colonies.

§ IV.—Chronographs and Chronoscopes.

Another use that has been made of the property possessed by electricity of propagating itself almost instantaneously, is to measure with precision very short intervals of time; for example, to measure the time which artillery projectiles take to clear the distance between the mouth of the cannon and the object struck. Instruments constructed for this purpose are called chronoscopes or chronographs, the second of the names being particularly reserved for those which register this interval and preserve a written mark of it.

Again, the name of Wheatstone presents itself in the first invention of this ingenious application of electricity. The chronoscope which he invented in 1840 was at first arranged in the following manner.

At the firing-station A, Fig. 424, is fixed a time-keeping apparatus C, having a weight for its motor, and capable of giving on two distinct dials, E D, the 10ths and 1,000ths of a second. An electro-magnet placed behind the box containing the wheelwork is provided with an armature, which is attracted when the current of the battery passes,

and then interferes with the motion and stops the clock. The result of this arrangement is that if the current ceases to act when the projectile starts, and is re-established when it strikes the target, the clock will go only during the transit—the precise duration of which it will consequently indicate.

This condition is realised in the following manner. The battery P communicates on one side with the chronoscope, and on the other side with the target M, and by a connecting wire with the cannon C the wire *f* passes in front of the mouth H of the piece.

A little before commencing the experiment the derived circuit is closed, and the current passes; and now the clock is stopped. The command to fire is then given, the wire is cut by the ball, the circuit is broken, the clock, let free, goes on until the moment when, by striking

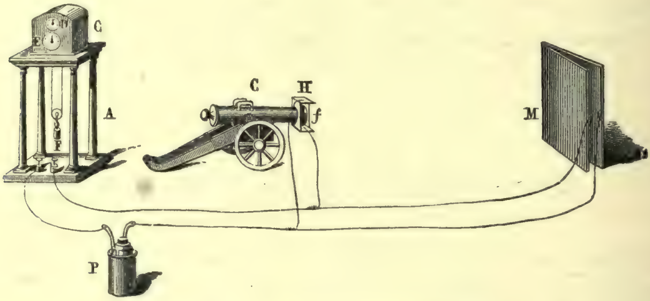


FIG. 424.—Wheatstone's chronoscope.

the target, the projectile brings into contact the two wires that are attached to it, and closes the circuit again. The clock is now stopped again, and the position at this moment of the needles on the two dials indicates, in seconds and fractions of a second, the exact duration of the flight.

Wheatstone himself perceived the disadvantages of this first arrangement. The magnetism remaining in the armature caused by the contact was maintained a little after the rupture of the current; on the other hand the motion of the needles was not immediately arrested upon the impact of the shot upon the target, and however small these differences might be, they were sufficient to render uncertain the indications of the chronoscope, especially for such small fractions of a second. The inventor was able to correct in some

degree these causes of error by employing in the beginning a current of very feeble intensity, and by so arranging the wires of the circuit that at the instant of the impact on the target a much stronger battery should be put into action to close the circuit and give the desired motion to the armature.

M. Hipp has also modified Wheatstone's chronoscope by making the motions of the clock and the indicating needles independent, so that whether the latter is at rest or no, the former continues going. The needles only move during the time of flight of the projectile.

We can only mention further :—M. Pouillet's chronoscope, which was founded on the amount of deviation which a current of known intensity can give to the needle of a galvanometer during the time the current is passing; the chronograph of Messrs. Bréguet and Constantinoff, which consists of a revolving cylinder, on the surface of which two pens, maintained by electro-magnets, trace in succession a line, when the projectile breaks two wires, at the time of departure and arrival, and so interrupts the circuits, and the position of the lines traced on the cylinder indicates what fraction of a turn the latter has made during the transit of the projectile; the chronographs of Captain Noble and Captain Navez, which have been used with success in numerous experiments on projectiles in this country, Belgium and Holland; the chronographs of M. Martin de Brettes and Boulanger, by means of which the initial velocity of a projectile and its velocity at any point of its path can be measured; and lastly, the levelling chronoscope of M. Bréguet. Space fails for a detailed description of these ingenious and useful apparatus, of which we have not even mentioned the whole. It is enough for our purpose to have explained by an example the possibility of making use of electricity for the precise measurement of elements so difficult to determine as those connected with projectiles. Wheatstone has applied chronographic methods to the study, and proof of the laws, of falling bodies.

Chronographs are also in daily use in astronomical observatories. A barrel which rotates and travels along at an even rate receives a puncture every second from a pointer or pen in electrical connection with the sidereal clock. In this manner a spiral line of dots is traced on the paper covering the barrel, and the commencement of each minute is marked by the absence of the dot. An observer at any of

the instruments in the observatory, who wishes to record the exact time at which a heavenly body passes the cross-wires of his instrument, sends a second series of currents through the same pricker, and by a subsequent inspection of the paper, the pricks of these dots compared with the second dots marked by the sidereal clock gives the time of the observation, which can be read to the $\frac{1}{100}$th part of a second.

CHAPTER VII.

ELECTRIC MOTORS AND ELECTRO-MAGNETIC MACHINES.

§. 1.—OSCILLATING ELECTRIC MOTORS.

IN telegraphy and in electrical horology the energy of the current of a battery or of induction currents is the source of the motions by which signals are made and transmitted—in one word, electricity is there employed as a mechanical agent or motor. But the employment of this force is not for the purpose of obtaining power, and indeed, it is generally only intended to regulate the play of another force, that of gravitation for example, whose influence it allows us to suspend and re-establish periodically.

But can electricity be employed directly as a prime mover? that is, take the place of steam in engines, which, having produced and stored a certain quantity of motion, distribute it to other engines, where it is transformed according to the needs of industry? This question has received several positive and practical answers, but we shall see in what way they are restricted.

Although different early attempts have been recorded, such as that of Salvator del Negro, of Padua, who in 1831 constructed a machine in which a magnet oscillated between the poles of an electro-magnet, and that of a German, Jedlick, who invented an electro-motive engine for direct rotation, it is to Jacobi of St. Petersburg, that the first serious invention of this kind must be ascribed. In 1839 a trial of his engine on a grand scale was made. "It was applied," says M. du Montcel, "to move a little boat with twelve persons on board, and having paddle-wheels for this purpose. He was able certainly to navigate the waters of the Neva for several hours, but the energy developed, although coming from a battery of 128 large Grove's

elements, never exceeded $\frac{3}{4}$ horse-power. So feeble a mechanical effort, developed by so energetic a current, discouraged the inventor completely, who since then has always considered this application of electricity as impracticable for industrial purposes."

We shall divide, as M. Verdet has done, the electro-motors into two classes, corresponding to two distinct types, that of the *oscillating engines* and that of the *rotating engines*, and we shall give an example of each of these types.

We shall first describe, in the words of M. Verdet, the principal characteristics of these two types of engines. In the *oscillating engines*, a coil or fixed electro-magnet attracts, when it is traversed by an electric current in the proper direction, either another coil, or an electro-magnet, or a magnetized bar, or even a simple piece of soft iron. When the movable piece comes nearly into contact with the fixed piece, the action of the engine moves a commutator, by which the attraction is changed into a repulsion, or replaced by the attraction of another piece situated on the opposite side. The direction of the motion is thus reversed, and these attractions being repeated indefinitely, we derive from them the same result as from the reciprocating motion of the piston of the steam-engine. In *rotating engines* the movable and fixed pieces are arranged on the radii of two concentric wheels, the passage of the current makes the movable wheel turn into a position of stable equilibrium, but at the moment this is attained the action of a commutator changes the direction of the action of the forces, and the motion of rotation is continued indefinitely in the same direction.[1]

M. Bourbouze's electro-motor belongs to the first type. The following are its essential arrangements:—

Two magnetising coils, EE, E′ E′ (Fig. 425), are arranged in pairs on each side of a vertical shaft surmounted by a beam, as in a steam-engine, and play the part of the cylinders, or body of a pump. In the inside, and up to half the height of the bobbins, are cylinders of soft iron, which become magnetised when the current from the battery passes through the wires of each coil. To the ends of the beam two rods are jointed, each of which carries two cylinders of soft iron, which move freely within the bobbins, and which are alternately attracted by

[1] Verdet, *Exposé de la Théorie Mécanique de la Chaleur,* lectures delivered in 1862 before the Chemical Society of Paris.

the magnetised bars when the current communicates to the latter their magnetising force. It is plain, then, that if the current passes successively and alternately through each pair of coils a reciprocating motion of the cylinders and their rods will be the result, and consequently an alternate circular motion of the beam. By means of a crank and an excentric this motion is transformed into a continuous circular motion of the driving shaft of the engine and its fly-wheel.

It remains to be seen how the current from the battery is introduced successively into the turns of each coil. For this purpose an excentric is attached to the driving shaft of the engine, which moves

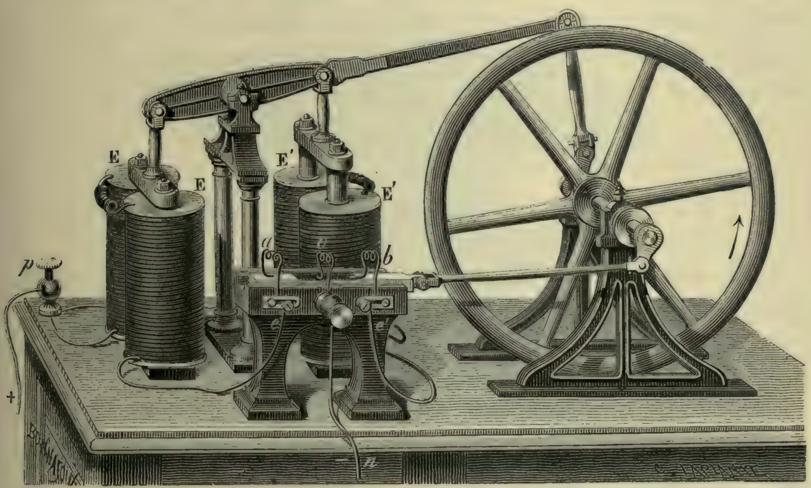


Fig. 425.—Bourbouze's electro-motor.

an ivory bar *aob*, covered in part of its length by a metal band along a slider.

The wire from the positive pole of the battery communicates through *p* with the two electro-magnets, and each of the latter with one of the ends of the inside of the slider, which in the centre *o* communicates on the other hand with the negative pole of the battery. Suppose the bar *aob* to occupy the position indicated by the figure.[1] The current then takes the path *pecaon*, for the

[1] A mistake has been made in the drawing with regard to the position of the lider. The wire *a* should touch the metal plate, while *b* rests on the ivory.

circuit is closed from p to n by passing through the coil of the bobbins E E. The excentric in moving to the right will open this latter circuit, but will then close that which passes by E′ E′, and then the soft iron of that electro-magnet will be magnetised in its turn.

So at each complete phase of the series the cylinders will be attracted to the left and the right, and the reciprocating motion of the rods and beam will be the result.

The two movable cylinders always remain very close to the interiors of the fixed cylinders; this is rendered indispensable by the known laws regulating the attractive force of magnets; this force increasing with extreme rapidity in proportion as the attracted and attracting masses more nearly approach to contact. The beam also is elongated by a good sized lever, so that the motion communicated to the crank of the driving shaft may have a sufficient amplitude.

§ II.—ELECTRO-MOTORS WITH CONSTANT ROTATION.

We now pass to the type of electro-magnetic engine which gives directly a continuous motion of rotation. We may take Froment's electro-motor for an example. Fig. 426 gives its general aspect.

Six pairs of electro-magnets, of which the figure only represents four, in order that the movable wheels and their armatures may be seen, are arranged along the radii of a circle, and are fixed to the framework of the engine carrying the driving shaft, which has its axis horizontal and passing through the centre of the same circle. Wheels concentric with this carry eight armatures of soft iron, arranged parallel to the axis of rotation, and which in the course of the motion place themselves in pairs with regard to the poles of the electro-magnets.

The eight armatures being distributed at equal intervals round the circumference of the movable wheel, and the number of electro-magnets similarly distributed being only six, when two armatures are exactly opposite the two electro-magnets E E, Fig. 427, the other armatures will be in front or behind according to the direction of the motion. Suppose this to be in the direction of the arrows or from

right to left, in this case the current of the battery is thrown into the coils E′ E′, and leaves the coils E E. The armatures next in turn in the direction of the motion come then to be attracted, and the motion will be continued in the same direction until the armatures are opposite the poles E′ E′. At this moment the current leaves these latter coils and passes on to E″ E″, and it will now be the turn of the next armature to be attracted, and so indefinitely. It is clear that during an entire revolution there will be as many attractions as the number of times the difference between the angles of separation of the electro-magnets and armatures is contained in the circumference,

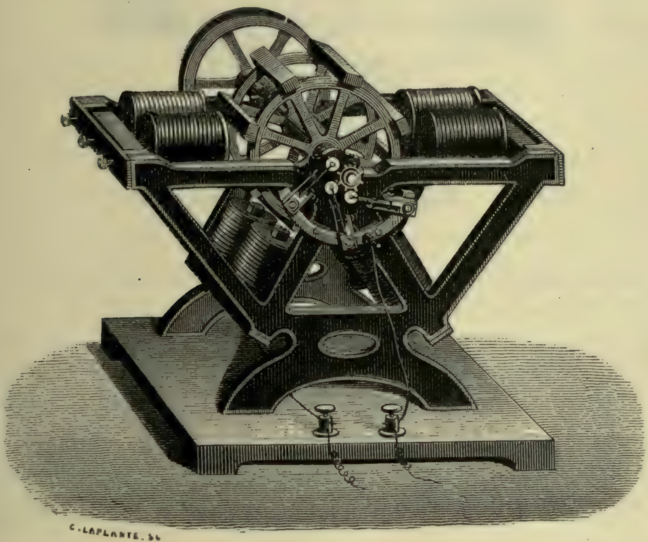


FIG. 426.—Froment's electro-motor with continuous rotation.

that is, twenty-four times (the difference between $\frac{1}{6}$ and $\frac{1}{8}$ being $\frac{1}{24}$). These alternate interruptions and passages of the current in the coils of the engine are obtained by means of a distributor, the arrangement and working of which may be easily understood from Figs. 427 and 428. This distributor consists of a wheel, R, centred on the axis of rotation and provided with eight teeth or pegs, equal, that is, in number with the armatures, and moving with them; this piece is in constant communication with the positive pole of the battery. Three springs, r, r', r'', fixed to an immovable circular sector, and each connected with the diametrically opposite pairs of the electro-magnets

by the wires f, f', f'', have their extremities placed in the same relation to the teeth of the wheel as the bobbins to the armatures of soft iron. When two armatures are exactly opposite, as at E E, the spring r, communicating with the electro-magnets E E, is in advance of a

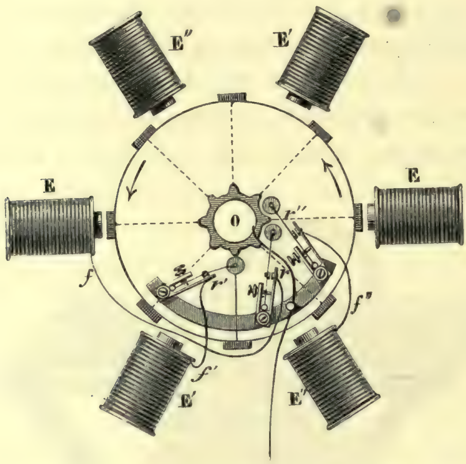


FIG. 427.—Froment's electro-motor: the action of the currents upon the armatures.

tooth which it has just quitted, while r' touches the preceding tooth and closes the circuit in the coils E' E'. After the twenty-fourth part of a turn r' quits the tooth, and then r'', by touching one in its turn, throws the current into the bobbins E'' E''. In one word, the circuit will be closed at each $\frac{1}{24}$th of a turn, and will pass by the spring,

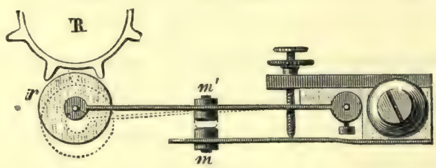


FIG. 428.—Distribution of Froment's electro-motor.

in contact with a tooth, to the bobbins in front of the armature by the same angular distance. The current returns to the negative pole, after having excited each pair of magnets, by a common wire. It does not cease moreover to act on one electro-magnet, until it has

passed to the next, an ingenious arrangement by which to lessen the spark which is produced by the starting of a fresh current. The oxidisation of the contacts caused by this discharge is thus greatly reduced.

§ III.—Various Applications of Electro-motors.

Electric prime movers can never successfully compete in power or economy with those in ordinary use, such as steam-engines. None have ever been constructed whose force exceeded a single horse-power. The reason of this is given by the principles of the mechanical theory of heat. The work of electro-motors is another form of the heat which the chemical actions of the battery develope; but since this method of production of heat is much more costly than that which consists in burning the coal necessary to the production of steam, it necessarily follows that the motive force of electricity is much less economical than that of steam. Experience has entirely confirmed this conclusion.

But if electrical engines cannot compete, in this respect, with the steam-engine and other prime movers; if their employment in manufactures appears impossible; there are services of another order which they can perform, whenever we require, not a particularly great force, but one of great regularity and velocity, and capable of acting at a great distance. Under these conditions they have a superiority which is increased by the ease with which they are set in action or stopped, the absence of all danger, and the small space they occupy. The inventor of the rotatory engine we have just described, M. Froment, made use of engines of this kind for the delicate operations of scientific mechanics, to which he devoted himself. He made use of them to move the wheels of his dividing engine, an instrument of such extreme precision that it can trace on a tube of glass divisions of excessive fineness, up to 1,000 marks in one millimetre. The precision and almost infinite delicacy of this instrument make it a marvel of mechanics, as may be judged by the following passage in a report by M. Dumas:—

"When we were assembled in London, on the occasion of the exhibition, M. Froment, in the middle of the meeting, drew out his

watch and said, 'It is now ten seconds to twelve. At the order of the clock of my laboratory at Paris my divider begins to move. The diamond traces five marks in the air to put itself in train and to warm the oil at the junctions and supports. It makes five useless marks on a plate of glass to show that it bites on it. It advances to the place where it has to begin its work; it traces its definite lines, the shortest for thousandth parts of millimetres—longer ones every five, and a little longer still every ten. It traces five hundred of these. It has finished its task, and remains in its place with its point in the air ready to recommence. In its turn, the clock indicates thirty seconds after twelve, so that when he returns to Paris the master

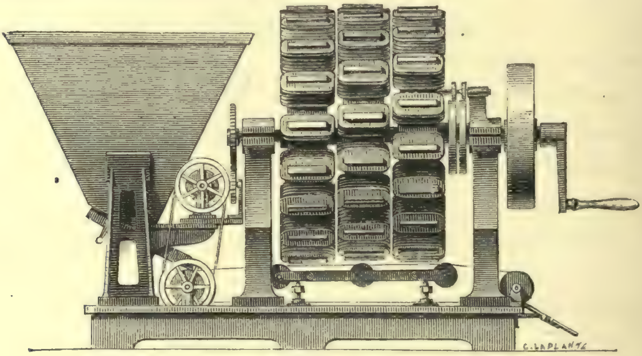


FIG. 429.—Chenot's electric sorter.

may assure himself that his electric slave has scrupulously obeyed him.'"

We now see that it is not power, but regularity and velocity that we may obtain from electricity, considered as a prime mover. It is this that has been required in telegraphy, and almost all the applications to which we have referred. We will give a few more examples.

The energy which excites an electro-magnet, whenever a current is thrown into the wires of its bobbins, had been used in that metallurgical operation which consists in sifting certain minerals—so as to separate the parts which are richest in metal from compounds of another kind. We can do this with those metallic oxides which become magnetic by roasting or reduction. A machine is made

use of, which was invented by a French engineer, M. Chenot, and which has received the name of *electric sorter*. Fig. 429 gives a general view of the apparatus.

On the left is a hopper filled with the powdered mineral to be sorted, and which drops down through the bottom of the hopper on to a metallic sheet rolled round two cylinders; from thence it is carried beneath three vertical wheels provided with electro-magnets attached to their circumference. These electro-magnets are connected with a commutator fixed to the common axis of rotation. When the motion brings this to the lower part of the apparatus they receive the current and become active. The magnetic part of the mineral only is attracted, and remains in contact with the electro-magnets until the moment when the current, ceasing to excite the latter, passes to the magnets, which replace them. Then the magnetic parts fall off, while the non-magnetic fragments are thrown out behind into a second hopper. The sorting is thus carried on continuously.

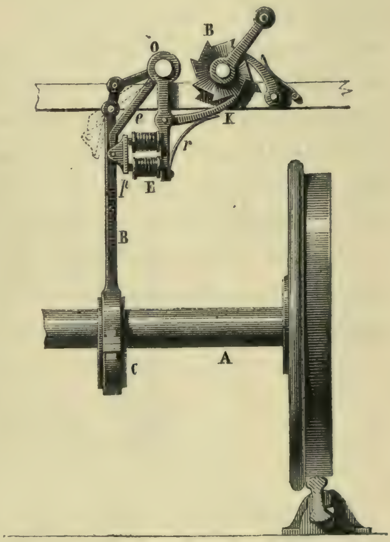


FIG. 430.—Achard's electric brake: mechanism for throwing out of gear.

Machines similar in principle but having *permanent* magnets are commonly employed for separating iron and steel filings or shavings from those of other metals in engineering workshops.

A modified form of this machine has been designed by the same inventor, in which the electro-magnets are fixed, and by means of a revolving collector, the magnetic or attracted material is swept off into a box placed for its reception.

A French engineer, M. Achard, has conceived the idea of borrowing from the active force of a train in motion the power necessary for gradually pressing the blocks of the brakes against the wheels of the carriages: and to put out of action the mechanism which would act in this way, he makes use of the attraction of an

electro-magnet. The following is one of the solutions of the problem he has proposed, and his system is at work on several lines.

The axle-tree A of the waggon carries an excentric C, which produces the reciprocating motion of the crank B and the oscillation of a shaft O, attached to the crank by one arm of a lever. This shaft also carries a lever *e*, whose extremity has a tongue of soft iron *p*, which places itself at each oscillation opposite the poles of an electro-magnet E. As long as the current is not thrown into this magnet it has no power of attraction, and it remains hanging by the rod which carries it; but if the brakesman, by means of a commutator within reach, closes the circuit of the battery, immediately the electro-magnet and the tongue are in magnetic contact, and both oscillate together. The suspending rod of the electro-magnet carries a catch K, which is kept by a spring *r* against the toothed-wheel B; one of the eight teeth of this wheel is thus pushed on at each oscillation, the wheel turns through an eighth of its circumference, and with it the mechanism which actuates the brake.

We need not here describe the brake itself, it is sufficient for our purpose to show how the throwing it into and putting it out of gear are effected by the passage or interruption of an electric current.

§ IV.—Magneto-Electric Machines.[1]

Few discoveries in physical science have been more important in themselves, or richer in practical results, than Faraday's discovery of the induction of electrical currents. Œrsted's grand discovery, which linked together electricity and magnetism, had already yielded a scientific harvest of uncommon richness. It led immediately to the construction of electro-magnets vastly exceeding in power any permanent magnets which were then known or have since been made. The multiplier or galvanometer of Schweiger supplied a new and important instrument for measuring electrical currents, which with a little modification became the electric telegraph. Faraday discovered the rotatory character of the reciprocal action of magnets and electrical currents; and Ampère showed that all the properties of a permanent

[1] Condensed from the report of a lecture, delivered before the Belfast Philosophical Society, by Dr. Andrews.—From *Nature*, June, 1875.

magnet could be explained on the hypothesis of electrical currents in a fixed direction circulating around the magnet. A problem which proved to be one of surpassing difficulty, and long baffled many of the most distinguished physicists of Europe—to obtain electrical currents by means of a steel magnet—was in 1831 completely solved in the exhaustive memoir by Faraday, in which he announced the discovery of the induction of electrical currents.

Soon after the announcement of these important results, Pixii constructed in Paris the first magneto-electric machine. The currents were obtained by the rotation of a powerful horse-shoe magnet in front

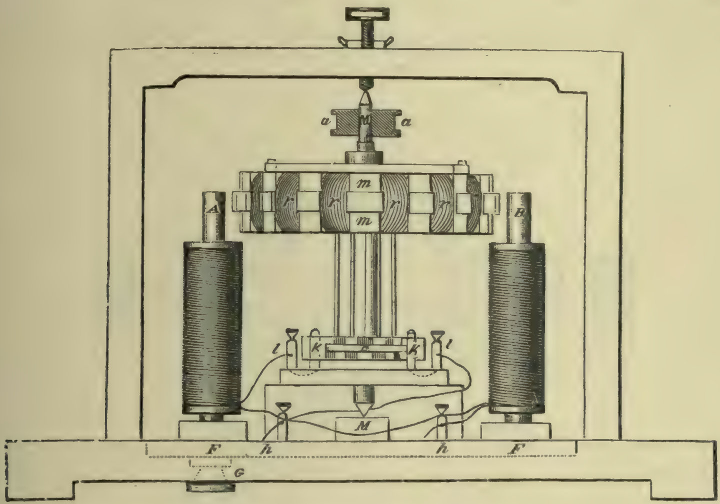


FIG. 431. - Pacinotti's machine.

of an armature composed of two short bars of soft iron with a connecting crossbar, the latter being surrounded by a long coil of copper wire covered with silk. The armature had, in short, nearly the form of a horse-shoe electro-magnet. With this machine electrical sparks were obtained, and water was freely decomposed. In the rotation of the magnet the faces of the armature or electro-magnet became successively north and south poles with intermediate conditions of neutrality, and the direction of the current changed at every semi-revolution of the magnet. An important modification of Pixii's machine was soon after made by Saxton, who caused the armature to revolve instead of the permanent magnet.

A large machine of this construction, exhibited some years ago at the Polytechnic Institution in London, was capable of igniting a short platinum wire.

Siemens' armature was happily applied by Wilde, in 1866, to the construction of a machine of extraordinary power. When the machine was in full action it melted a rod of iron 15 inches in length and a quarter of an inch in diameter, and gave the most brilliant illuminating effects when the discharge took place between carbon points. As nearly as could be estimated, the mechanical force absorbed in producing these results was from eight to ten-horse power. Wilde's machines have been successfully employed by Messrs. Elkington for the precipitation of copper and other metals, and he has lately proposed some important modifications to adapt them to the production of the electric light.

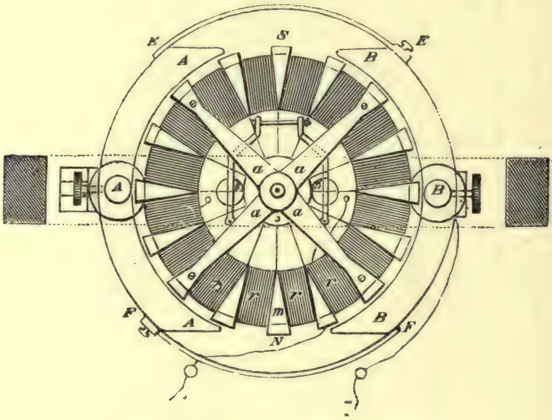


FIG. 432.—Pacinotti's machine (plan).

Some years before Wilde's experiments were published, Holmes had constructed on the Saxton principle a powerful magneto-electric machine, which has been successfully used at Dungeness and other lighthouses, and machines differing little from Holmes's are employed in some of the French lighthouses. In Holmes's original machine forty-eight pairs of compound bar-magnets were arranged for the armatures (160 in number) to revolve between the poles of the magnets, and by a system of commutators the current was obtained always in the same direction. French engines on this principle have been recently constructed by a commercial company, the Alliance, which has

brought them to a high degree of power. Fig. 434 represents one of these apparatus as at work in the lighthouse of Hève, on the coast of La Manche.

A very solidly-made framework of iron carries several series of eight horse-shoe magnets ranged as radii of as many circumferences as there are bobbins, opposite to whose armatures of soft iron their poles are placed. The eight pairs of bobbins of each series of magnets are supported on bronze wheels, and the ends of their wires are attached to wooden discs or plates fixed to the wheels. A single axis of rotation turns on fixed sockets in the framework and carries with it all the discs and bobbins, whose armatures thus pass rapidly before the poles of the magnets. An indefinite series of induced currents results, which by the arrangements adopted are all in the same direction, and together form what may be called a continual source of electricity. By collecting this electricity by means of two wires running to the carbonholders of an electric lamp, a light of considerable intensity is obtained.

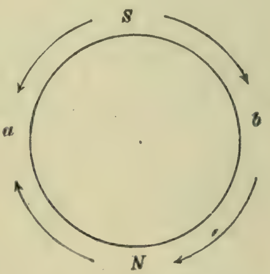


FIG. 433.—Course of the current in Pacinotti's machine.

The first suggestion of a magneto-electric machine capable of giving a continuous current *always in the same direction* is due to Dr. A. Pacinotti, of Florence, whose essential feature was a novel form of armature to which he gave the name of "transversal electro-magnet." This armature was formed of a toothed iron ring, *m m* (Fig. 431), capable of rotating on a vertical axis, M M, and having the spaces between the teeth occupied by helices of copper wire covered with silk. The wire of the helices was always wound in the same direction round the ring, and the terminal end of each helix was brought into metallic connection with the adjoining end of the wire of the succeeding helix. From these junctions connecting wires were carried down parallel to the axis of the machine, and united to insulated plates of brass, of which a double row, as shown in the figure, were inserted in a wooden cylinder, *c*, which was itself firmly attached to the lower part of the axis. The current entered through the successive brass plates as they came into contact with a small metallic roller, *k*, which was in communication with one pole of a voltaic battery. At the point of junction with the

wires of the helices, the current from the battery divided into two parts, which respectively traversed in opposite directions the connected helices, each through a semi-diameter of the ring, and finally left the machine on the opposite side by a second roller, *k*, which was in connection with the other pole of the battery. When the connections were made, the iron ring began to rotate round its axis with considerable force. In a trial in which the current was supplied by four small elements of Bunsen, a weight of several kilogrammes was raised. In the apparatus as actually constructed, the poles of the electro-magnet

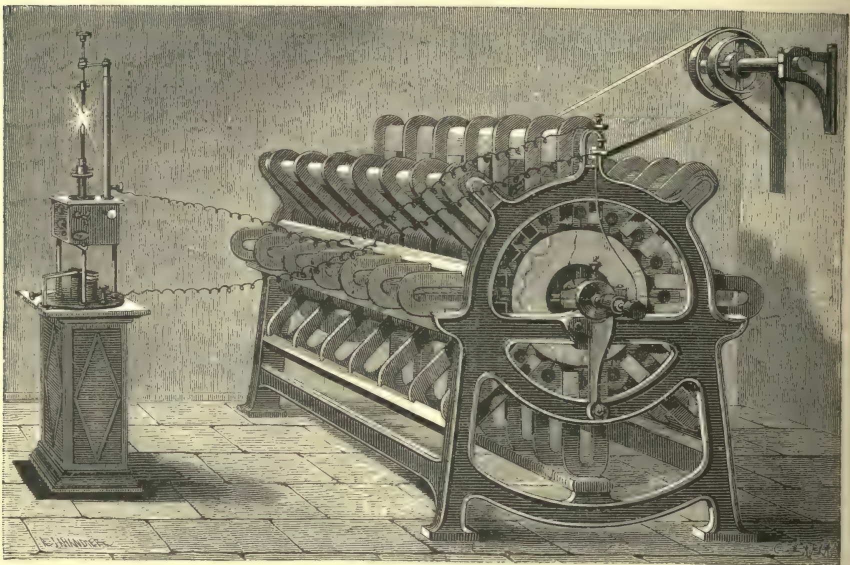


FIG. 434.—Alliance magneto-electric machine.

were enlarged by the addition of two segments of soft iron, AA, BB (Fig. 432), which extended over the greater part of the iron ring. The details of the construction of the transversal electro-magnet will be easily understood from the plan given in the figure.

The results he obtained were not great, but were sufficient to enable him to announce that a magneto-electric machine could be constructed which would have the advantage of giving the induced currents all in the same direction, without the help of mechanical arrangements to separate opposed currents or to make them conspire with one another.

In 1871 M. Jamin communicated to the French Academy of Sciences a short note by M. Gramme on a magneto-electric machine which gave electrical currents always in the same direction by the revolution of an electro-magnetic ring between the poles of a permanent magnet. The construction of the electro-magnetic or ring armature in Gramme's machine differs in some mechanical details from that of the transversal electro-magnet of Pacinotti, and the serious mistake of applying the rubbers which carry off the current at the wrong place is avoided. We must therefore regard the Gramme machine as the first effective magneto-electric machine constructed to give continuous currents all flowing in the same direction.

The construction of the ring armature in Gramme's machine will be readily understood from Fig. 435, in which it is represented in

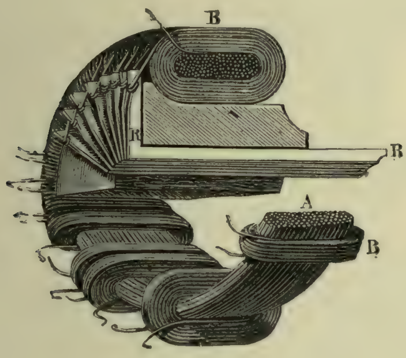


FIG. 435.—Gramme armature.

different stages of its construction, so as to show the manner in which the principal parts are connected. At A a section of the iron ring itself is shown, composed of a bundle of iron wires; at B B the helices, or bobbins, are seen both in section and detached; and at R R the form is shown of one of the insulated copper conductors, to which the contiguous ends of the wires of the helices are attached, and from which the current is drawn off by means of rubbers or brushes formed of flexible bundles of copper wire. These brushes are so applied at the neutral positions of the ring that they begin to touch one of the conductors, R, before they have left the preceding one. In this way no actual break or interruption occurs in the current. The permanent

magnets employed in the smaller Gramme machines are on the improved construction of M. Jamin.

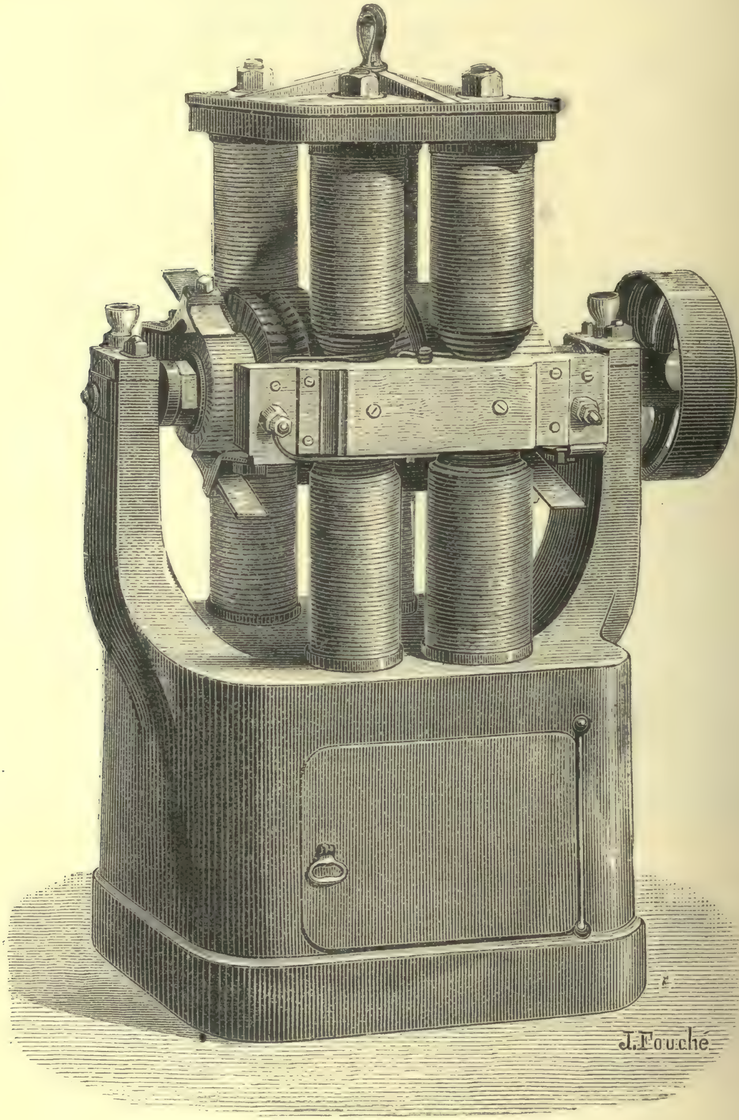


FIG. 436.—Gramme machine for metallic precipitations.

Fig. 436 represents a machine constructed with electro-magnets in 1872 by M. Gramme, which, with six others of the same kind, is in

use in the well-known galvanoplastic establishment of Christofle and Co., of Paris. These machines weigh 750 kilogrammes, and the weight of copper used in their construction is about 175 kilogrammes.

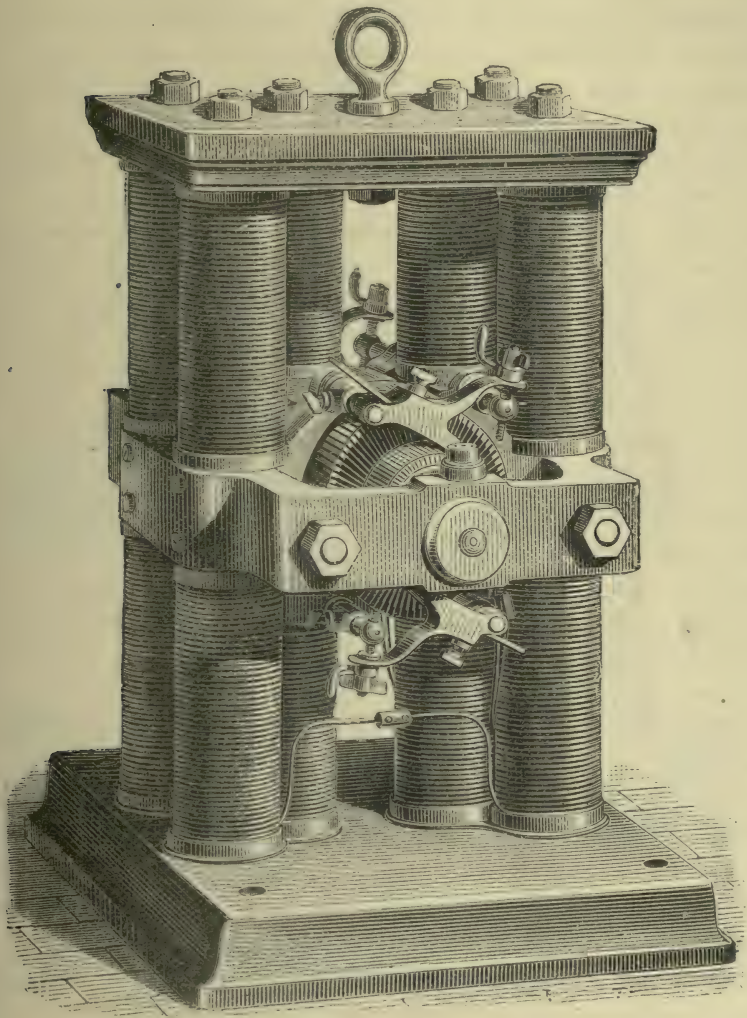


FIG. 437.—Gramme machine for electric light.

With a small engine of one-horse power, one of them will deposit 600 grammes of silver per hour. By some recent modifications in its construction this machine has been improved so as to increase the

weight of silver deposited per hour to 2,100 grammes, or above $4\frac{1}{2}$ lbs. In Figs. 437 and 438 we have the forms of the Gramme machine now in use for the production of the electric light. They are improvements on the machine which was tried on the Clock Tower of Westminster Palace. It produces a normal light of 500 Carcel burners; but, by augmenting the velocity, it is asserted that the amount of light may be doubled. It does not become heated, nor does it produce any spark where the brushes are applied.

In Fig. 438 we have the latest improvements devised by M. Gramme for producing the electric light. In this machine there are only two bar electro-magnets and a single movable ring placed between the electro-magnets. Its weight is 183 kilogrammes, and the entire weight of copper used in its construction, both for the ring and for the electro-magnets, amounts to forty-seven kilogrammes. Its normal power is about 200 Carcel burners, but this can be greatly augmented by increasing the velocity.

By uniting two or more machines together, electrical currents of high tension may be obtained. But a more useful arrangement is to divide into two each ring, so that the two halves may be joined either for quantity or tension, and varied effects thus obtained from the same machine. This is effected in the following manner. Suppose the machine to contain sixty bobbins or helices round the ring. If the entrance of the thirty alternate bobbins is placed on one side of the ring and of the thirty other bobbins on the other side, there will be in reality two ring-armatures in one, interlaced as it were into each other; and by collecting the currents by means of two systems of rubbers, one to the right and the other to the left of the ring, we may obtain from each one half of the electricity produced by the rotation of the ring. By applying this principle to machines for producing the electric light, the same machine may give two distinct lights instead of one. In its industrial applications, this is a point of capital importance. The use of the electric light is at present greatly interfered with by its excessive brightness, and the deep shadows which by contrast are produced at the same time. These defects will be to a large extent remedied by the use of two lights, so that the shadow from one may be illuminated by the other. It is proposed to use four electric lights, each of the strength of fifty Carcel burners, for lighting foundries and large workshops.

The following is a description of Messrs. Siemens' electric light apparatus. It is a complete apparatus by itself, in which the core of the armature is fixed, and the wire-helix alone caused to rotate. By fixation of the armature core great inductive power is obtained, and consequently powerful currents. With about 380 revolutions of the wire-helix per minute, and nine to ten horse-power, a light equal to 14,000 candles is obtained.

In this machine (shown in Figs. 439 and 440) the conductor, by the motion of which the electrical current is produced, is of insulated

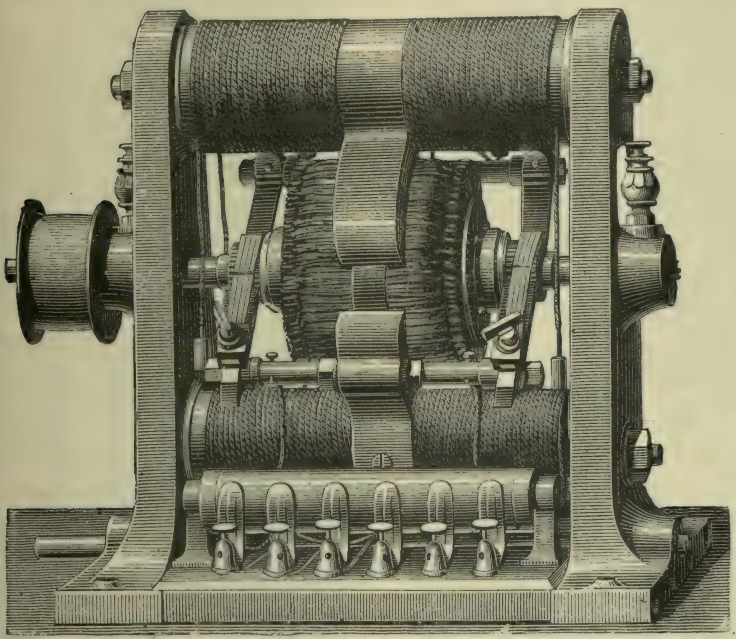
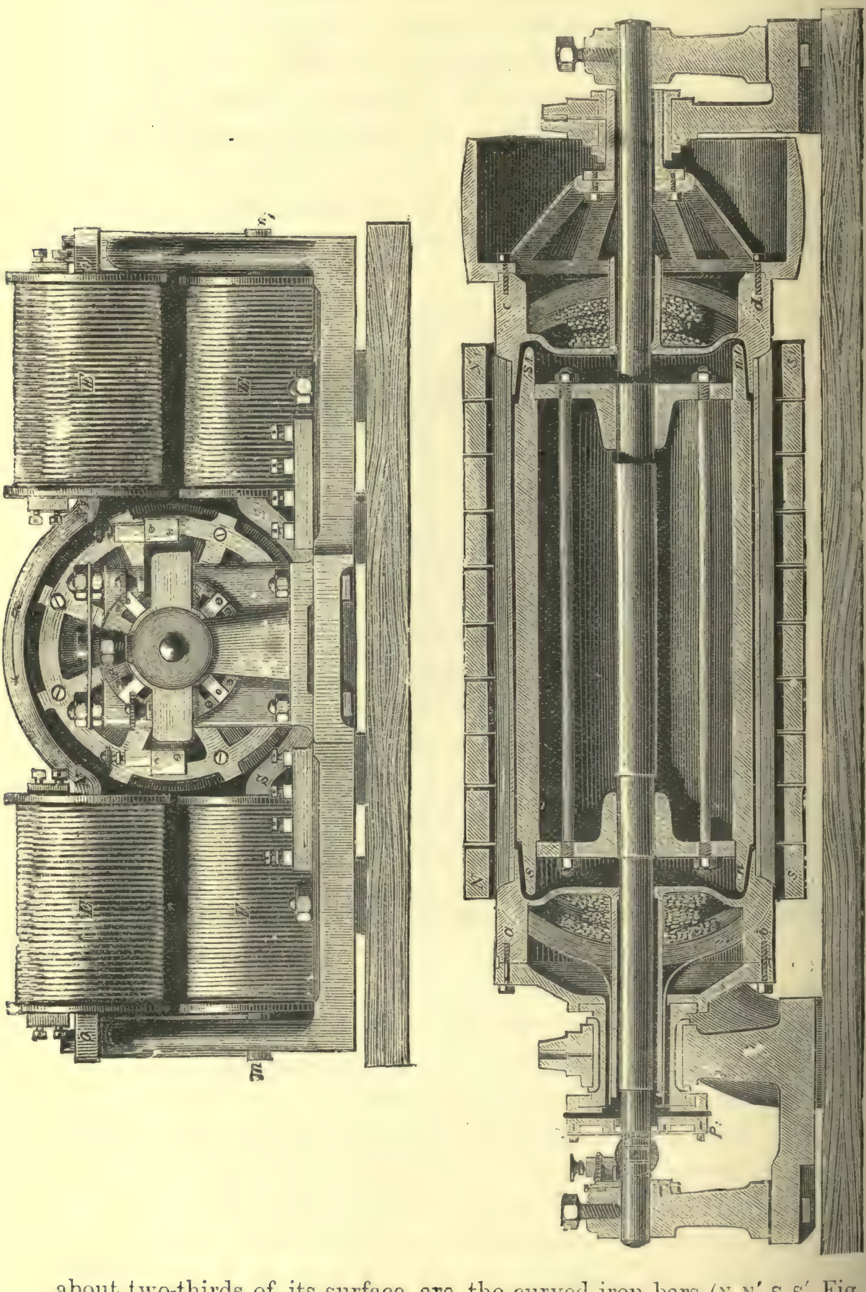


FIG. 438.—Gramme machine for electric light (latest form).

copper wire, coiled in several lengths, and with many convolutions on a cylinder of thin German silver, and in such a manner that each single convolution describes the longitudinal section of the cylinder. The whole surface of the metal cylinder is thus covered with wire, forming a second cylinder closed on all sides (*a, b, c, d*, Fig. 440).

This hollow cylinder of wire incloses the stationary core of soft iron (*n s s′ n′* Fig. 440) which is fixed by means of an iron bar in the direction of its axis, prolonged at both ends through the bearings of

the wire cylinder to standards. Surrounding the wire cylinder for



FIGS. 439 and 440.—End elevation and longitudinal section of dynamo-electric light machine.

about two-thirds of its surface, are the curved iron bars (N N′ S S′ Fig.

440), separated from the stationary iron core by space only sufficient to permit the free rotation of the wire cylinders. The curved bars are themselves prolongations of the cores of the electro-magnets (E E E E), and the sides of the two horse-shoe magnets (N*o*—S, *m* and N′*o*′—S′,*m*′) are connected by the iron of the two standards (*om* and *o′m′*).

As the coils of the electro-magnets form a circuit with the wires of the revolving cylinder, the revolution of the latter causes a powerful current to pass into the electro-magnetic coils, this again inducing a still more powerful current in the wires of the cylindrical armature. The iron core of the cylindrical armature being very close to the poles of the electro-magnets, becomes itself an intensely powerful transverse magnet of opposite polarity to the electro-magnet. The cylinder of wire thus revolves in a very intense magnetic field.

These electrical currents are collected on two metal rollers or brushes, so that at two points diametrically opposite the single sectors pass under the rollers or brushes with elastic pressure giving up to them their electrical charge.

A slight increase of speed in the rotation of the wire cylinder is followed by a considerable increase of current, but as the current increases, so does the resistance to rotation; and this very rapidly. In addition to this, heat is developed to such an extent, that care must be taken not to exceed a certain limit, otherwise, the insulation of the coils would be destroyed. Were it not for this drawback almost any amount of current might be produced with suitable driving power.

As the external resistance affects the strength of the current the speed must be varied accordingly, being greater as the external resistance is greater, and *vice versâ*. With an electric lamp in a circuit of small resistance, if the machine is intended to work continuously, the revolutions of the wire cylinder per minute should not exceed 370 to 380. The temperature of the machine will then be at a maximum in about three hours; and during work will remain constant. At this speed the driving power is about eight indicated horse-power, while the intensity of the light, unaided by reflector or lens, has been shown by various photometers to be equal to 14,000 normal English candles. A more intense electric light cannot be obtained, as any increase in the current splits up even the best carbon.

The conducting wires from the machine to the lamp should be of copper, offering very little resistance, and at the same time possessing

a high electrical conductivity. If the lengths of the two wires do not together exceed fifty-five yards, then a wire of 0·157 inches diameter and of high conductivity will suffice. For longer distances it is advisable to use a strand of larger diameter.

The lamp used with the machine is regulated without clockwork, as the employment of the latter has not only been a source of numerous failures and difficulties, but is liable to disarrangement upon the least rough usage. The lamp of itself regulates the carbon points, keeping them at a uniform distance, and thus a perfectly steady light is produced.

CHAPTER VIII.

THE ELECTRIC LIGHT.

§ I.—Regulators of Electric Lamps.

AFTER the light of the sun the most dazzling light that can be produced artificially is the electric light. This is obtained by the incandescence of two carbon poles completing the circuit of a powerful battery or of a magneto-electric machine. Attempts have been made to utilise this light for a great number of industrial, military, and scientific purposes, as also for the lighting of streets and squares, for works which must be continued through the night, for submarine constructions, works in the galleries of mines, military and marine recónnoitring by night, lighthouses, and for particular effects of decoration in theatrical representations. In most of these various applications success has crowned the endeavours that have been made, but not without calling for special researches and the overcoming of special difficulties.

One of the chief of these difficulties consisted in the discontinuity of the light caused by the separation of the poles due to the combustion of the carbon. It is known, in fact, that when the light is produced, the current carries over from one cone to the other excessively fine portions of matter—one of the carbons appears to elongate at the expense of the other; but in reality, as combustion is in question, the distance between the two points goes on increasing; in proportion as they are blunted the current grows weaker, the intensity of the light decreases, and at the end of a certain time ceases altogether. In the case in which the current employed is that of a galvanic battery, and is therefore always in the same direction, the wearing away of the cones of carbon is in the ratio of one to two; the positive pole being used the quickest.

If the instrument employed is an magneto-electric induction apparatus, in which the current changes its direction at each revolution, each of the carbons is alternately positive and negative; the wearing away is the same. In every case it is obviously necessary, in order to obtain a continuous source of light, to maintain the points of the two cones at a sensibly constant distance; and this is attained by means of apparatus called *regulators.*

The principle by which the regulators of the electric light work is that the current itself regulates the distance between the carbons; it is especially charged to bring together the points, and to keep them at a suitable distance. For this purpose it is made to traverse the coils of the bobbin of an electro-magnet, and an armature of soft iron comes in contact with its poles when the current has a sufficient intensity—that is to say, so long as the extremities of the carbon cones are sufficiently near to give rise to a light of suitable intensity.

If we once understand the principle of the regulators, the first idea and first realisation of which are due to Léon Foucault, there will be no difficulty in understanding the mechanism and working of the apparatus in general use.

First let us speak of Duboscq's regulator, which has been invented for using the continuous current furnished by the battery. This clever and experienced constructor had in view chiefly the scientific applications of the electric light; and those who have attended the public lectures on physics at the Sorbonne and elsewhere may remember having seen it at work in the experiments or in projecting microscopic objects on the screen. The carbon poles thus supplied the place of the absent rays of the sun.

Fig. 441 represents this regulator.

c and c' are the two carbon points between which the luminous arc leaps. The current which causes the production of the light leaves the positive pole of the battery to enter by the binding screw R, passes through the wire of the bobbin of the electro-magnet BB, the rod T passes on from c to c', and thence, by the rods T′ and S, to the screw R′, which is in communication with the negative pole to the battery.

A movable contact K, placed opposite the soft iron nucleus of the electro-magnet, is attracted by the poles of the latter when the current preserves a sufficient intensity, that is to say, when the carbons

are sufficiently near together. The contact then rests on the horizontal arm of the bent lever L, movable about F′. The vertical arm L of this lever, by the intervention of a shorter lever *lm*, stops a toothed wheel, which carries the regulating "fly" *g* of the wheel-work. The motion of the wheel-work is then arrested as long as contact continues.

The wearing away of the carbons, and their consequent too great separation, enfeebles the current, the antagonistic spring *s* carries away and separates the armature from the poles of the electro-magnet, and the wheel-work is set free. The wheels *pp′* are then put in motion, and the two racked rods S and T move in opposite directions; the carbons *c* and *c′* are drawn together, the current and the luminous arc recover their original intensity, which causes a fresh contact of the armature and stoppage of the wheel-work, and so on. The toothed wheel which drives the rack T has a radius double of that of the wheel which brings down the rack S. In this way the positive carbon moves twice as far as the negative carbon, and the luminous arc remains at a constant height.

We must pass on now to Foucault's and Serrin's regulators, both used in the industrial applications of the electric light. Fig. 442 represents the first of these apparatus.

The racks H and D which carry the carbons are arranged pretty nearly as they are in Duboscq's regulator; only the toothed wheels that move them can turn in two opposite directions, because they are connected with a double clockwork movement, one part of which is stopped, while the other goes. On this account the carbon cones are able either to approach each other, or, on the contrary, to separate. The automatic recoil of the carbons dispenses with their being put in position by the hand, and prevents their accidental contact, from which would result an extinction of the luminous arc.

The two wheel-work arrangements are provided with two fly-wheels or star-shaped regulators *o o′*, on each of which the head *t* of the lever T, acts alternately, obtaining its motion from the armature of the electro-magnet E. When the "fly" *o* is caught, the corresponding wheel-work is stopped, but then *o′* is set free, and its wheel-work is put in action; an inverse motion of the armature and the lever T produces the contrary effect. We will now explain under what circumstances, and by what mechanism, these contrary motions are produced.

F is the armature which the poles of the electro-magnet E draws into contact, provided that the intensity of the current depending on the distance of the carbons is sufficient to overcome the power of the antagonistic spring R. This latter does not act directly on the branch P of the lever F, but on a lever situated above, and movable at X. When the current has its normal intensity, the rod T is vertical, and the two trains of wheels, both stopped, are immovable. When the current grows weaker F leaves the poles, the branch T inclines towards the right, stopping the fly-wheel o', and the wheel-work to the left of the figure, which draws the carbons together, is put in motion. The current gradually regains its strength, the lever moves in the opposite direction, and if the intensity increases beyond a certain limit, that is to say, if the carbons approach each other more than is necessary, the wheel-work producing a recoil is put in motion, while the other is stopped. By the aid of a screw, which acts on a lever R, the tension of the spring can be suitably regulated to the intensity of the current employed. Finally, by modifying one of the parts of the mechanism, we can make the velocities of the two points equal, or make the positive carbon move twice as fast as the other. This regulator can therefore work just as well with a battery as with a magneto-electric machine.

The lever X, which acts on the branch P of the armature, has its under surface slightly curved, so that the point where the lever acts changes in position; the action of the spring is therefore also variable, and varies according to the intensity of the current. Since the curvature in question is very slight, the resulting oscillatory motions of the armature are themselves very small, so that the approach and separation of the carbons takes place by almost insensible gradations, and there is a remarkable constancy in the light.

In Serrin's regulator (Fig. 443) the upper carbon-holder A B has a rack which works into the toothed wheel F; it tends to descend by its own weight, and to make the carbon C descend, and also to turn the toothed wheel. On the axis of the latter is fixed a pulley G, which by means of a chain and a turning pulley J communicates an ascending motion to the rod K K, which carries the lower carbon. This motion takes place so long as no current passes, and thus draws the carbons into contact. When, however, the circuit is closed and the current is introduced into the apparatus, the electro-magnet E

attracts a soft iron cylinder A; this latter forms part of an oscillating

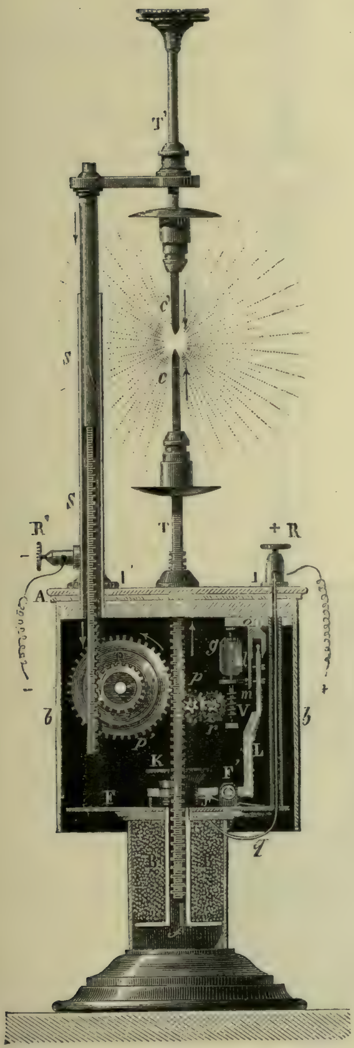


FIG. 441.—Duboscq's regulator for the electric light.

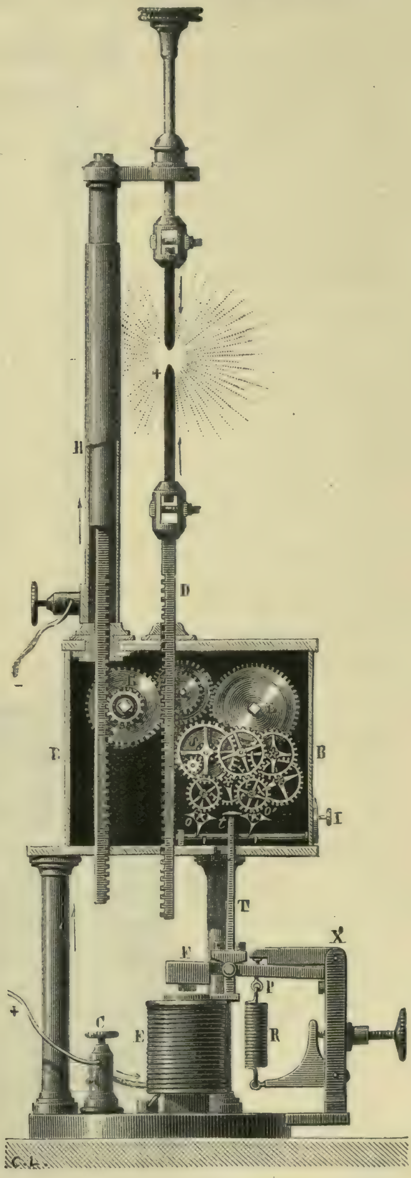


FIG. 442.—Foucault's regulator.

parallelogram T A S R, which descends with the armature, and draw

with it the carbon carrying tube K K, to which it is attached. A triangular-shaped piece *d* of the oscillating system then comes against

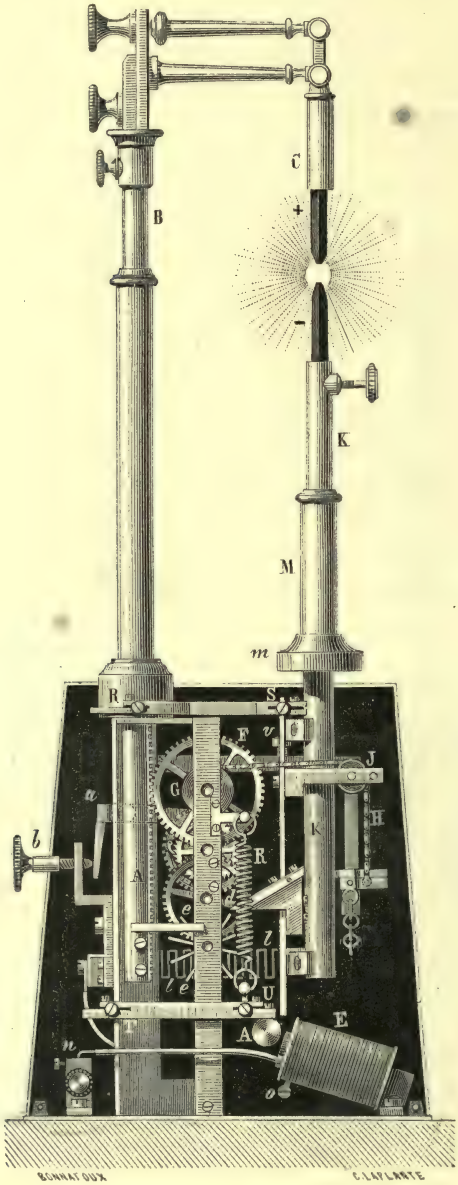


FIG. 443.—Serrin's regulator.

one of the tongues of the catch-wheel *e e*, which causes a stoppage

of the wheels. The two carbons then separate, and an instantaneous formation of the voltaic arc takes place, and the lamp now begins to work.

But by degrees the carbons consume, and their distance increases, the voltaic arc grows larger, and the intensity of the current diminishes by reason of the increase of resistance; the energy of the soft iron of the electro-magnet thereby grows less, and the attraction is diminished upon the armature A, which then yields to the action of the antagonistic springs R. The oscillating system then rises, draws up the catch *d* so that the catch-wheel is disengaged, and the wheels work again. Thus the carbons approach each other once more, increasing the intensity of the current and therefore the attraction of the armature, and so on indefinitely until the carbons are too much worn away and have to be renewed. The working of the lamp and the duration of the light produced are thus insured continuously, and depend only on the carbons being selected of the proper length, considering the time for which the illumination is to continue.

The current arriving by the connection to the tube A B, passes from the upper to the lower carbon, follows the tube K K, and by an undulating band *e* enters the bobbin of the electro-magnet; whence it goes to the binding-screw *n*, which in turn communicates with the negative pole of the battery or of the magneto-electric machine.

We should add that the diameters of the wheels F and the pulley G are calculated to have the same ratio as the distances passed over by the carbons, which will be unequal if their wearing away is so, so that the luminous point may always be maintained at a constant height.

§ II.—Electric Lighthouses—Various Applications of the Electric Light.

One of the most important applications of the electric light is certainly that of the illumination of lighthouses. First-class oil lamps, thanks to the admirable lens arrangements of Fresnel, have, in ordinary times, a range quite sufficient for the service of the coasts, but not so on nights when the air is foggy, and which are precisely

those on which it is of the greatest importance to sailors to be sure of their position. The increase of the number of Carcel lamps does not solve the difficulty, for the range depends not only on the apparent diameter of the light, but on its intrinsic illuminating power. The employment of the electric light, the intensity of which is so considerable, naturally suggested itself; but its application was not possible until a suitable regulating apparatus and machines capable of producing a sufficient amount of light had been discovered. Regulators such as Serrin's or Foucault's satisfied the first of these conditions; Magneto-electric machines have enabled us to satisfy the second.

The Alliance magneto-electric engines of the lighthouse of La Hève, on the Straits of Dover, are set in motion by two steam-engines of five-horse power between them; with a velocity of rotation of four hundred turns a minute the maximum intensity is obtained. The light (reduced to the horizon) produced by a machine with four discs, equals that of 3,500 Carcel lamps; with a machine of six discs, the effect of 5,000 lamps is obtained, with a range of twenty-seven nautical miles, or fifty kilometres. This powerful source of light results from the association of the induced currents which arise from the instantaneous action of forty-eight magnets on the ninety-six moving bobbins in each magneto-electric machine.

Four of these Alliance machines are at work in the lighthouse of La Hève. All the apparatus is in duplicate, in order that the immediate substitution of one lamp for another may not produce any discontinuity of the light. The lamps are set upon little pairs of rails, ending in the centre of the lenticular apparatus, fixed one alongside the other in the same lantern. The regulators employed are Serrin's. This new method of illuminating lighthouses has been recently adopted along the Suez Canal.

Not only does the electric light produced by electro-magnetic machines surpass in intensity that afforded by oil-light apparatus in the ratio of five to one at least, giving a light equal to 400,000 candles, but it is also more economical.[1] While a lighthouse provided with ordinary first-class lamps costs three francs seventy cents an hour, an

[1] M. Van Malderen is about to construct a new pattern of engines with four discs, which will be more powerful, with equal velocity, than the old ones with six discs. They give the light of 230 Carcel lamps instead of 180.

electric lighthouse such as those of the Hève only costs two francs seventy-nine cents with a machine of four discs; and for an equal intensity the net cost is only one-seventh. This, however, is for a service in which there must be no interruption. In industrial applications the net cost would be certainly still less, provided always that the light was employed not less than ten hours a day. In the cases where the motive force can be borrowed from powerful engines which are working for other purposes, as in many manufactories, the electric light—as M. Roux[1] also has remarked—would scarcely cost any more than the original outlay for the magneto-electric machine and the regulator.

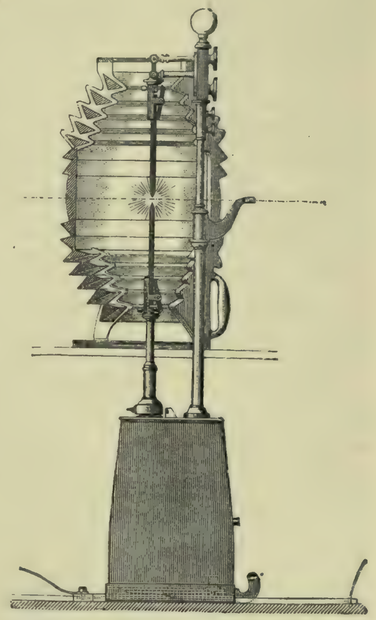


Fig. 444.—Electric light apparatus in the lighthouses of the Hève.

In the new opera-house in Paris the electric light is thrown upon the stage by means of a Bunsen battery of 360 elements which is established in a room on the ground-floor. M. Dubosq has here arranged six tables, each supporting a Bunsen battery of sixty elements. This battery is placed upon the table, which is made of very thick unpolished glass that cannot be injured by the acids. The elements are arranged in four rows of fifteen each. The table is provided underneath with a board which supports a large rectangular basin, in which the plates are placed after they have been used. The jars of the battery, filled with nitric acid, are, after being used, placed in a tub containing the acid, and closed with a wooden lid.

In order to work a battery of such power under favourable conditions, M. Dubosq has had to make special arrangements for the

[1] *Les Machines Magnéto-électriques Françaises, et l'Application de l'Electricité à l'Eclairage des Phares,* two lectures delivered before the Society for the Encouragement of National Industries.

preparation of the sulphuric acid solution as well as for the zinc amalgams necessary to put the system of batteries in action.

At the right corner of the electric room is a large reservoir, of the capacity of about one cubic metre, where water mixed with one-tenth of sulphuric acid can be stored. A spigot permits this liquid to run into a vertical siphon formed of a large tube, into which an areometer is plunged to ascertain its quality, and make sure that the preparation has been made in the proper proportions. The reservoir is furnished at its lower part with an earthenware pipe, which is conducted along the walls of the room opposite the six-battery tables. Beside each table an earthenware spigot enables the operators to run the liquid into earthenware jugs, from which the battery-jars are filled with the liquid.

M. Dubosq has obviated the dangerous action of the nitrous vapours by placing here and there upon the piles saucers containing ammonia, which condenses them.

The electric wires are conducted along the wall at the bottom of the room, where they traverse six galvanometers (Plate XX.). Each of these galvanometers indicates, by means of the needle with which it is provided, the condition of the battery to which it corresponds. The six insulating wires, after leaving the six galvanometers, pass along the walls to the stage, where the currents which they carry may be utilised either singly or by twos or threes, according to the degree of intensity which it is wished to give to the light. The distance which the current runs from the electric room to the most distant point of the stage is about 122 metres; the total length of all the wires is about 1,200 metres.

M. Dubosq, imitating the system of telegraphic wires, makes use of the earth as a return current; one of the poles of each battery is in communication with the iron of the building. Without this arrangement it would have been necessary to double the length of the wires.

In most instances M. Dubosq places his electric lamp on one of the wooden galleries which run along the higher regions of the scenery above the stage. It is from this artificial sky that he darts upon the ballet the rays of his electric sun, or, decomposing the light by means of the vapour of water, he throws upon the stage a veritable rainbow, as in *Moses;* again, it is thus that he causes the light from the painted windows to fall upon the flags of the church where

PLATE XX. – VIEW OF THE ELECTRIC ROOM AT THE NEW OPERA HOUSE IN PARIS.

Margaret is in the clutches of remorse. Sometimes the electric apparatus is placed on a level with the stage, when it is sought to produce certain special effects, such as that of the fountain of wine in Gounod's opera.

Electric illumination has been applied to ships, and the experiments that have lately been made in the steamers of the *Compagnie Générale Transatlantique* have proved so successful, that the time cannot be far distant when every ocean-going ship, whether belonging to the royal navy or to the mercantile marine, will have to carry an electric light for showing rocks or icebergs two or three miles ahead,

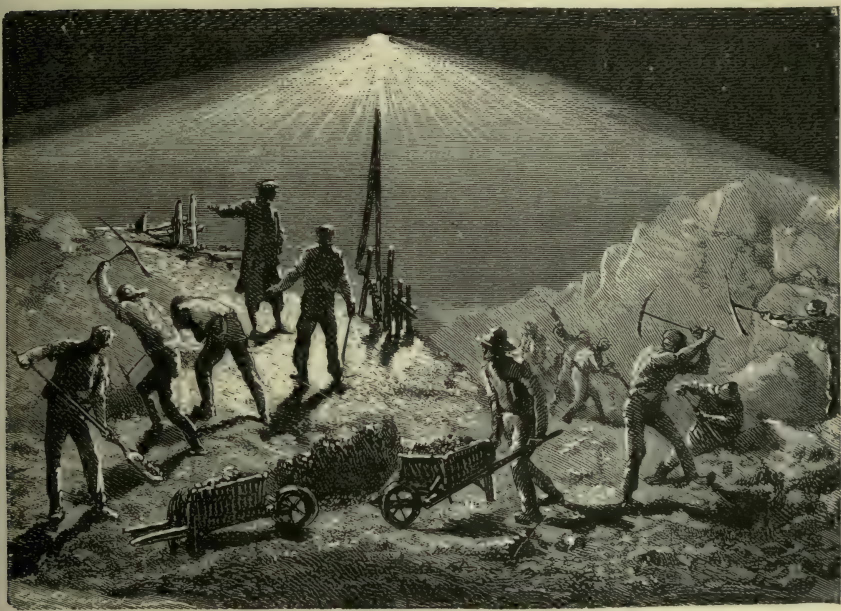


FIG. 445.—The electric light applied to works at night.

in order to avoid collisions, and to facilitate entering or leaving port.

The illumination of the galleries of mines by electricity has also been perfectly successful. Experiments have been made during seventeen days and nights in the slate quarries of Angiers under the direction of M. Bazin, and they have given excellent results.

We must not forget the employment of this powerful means of illumination in works carried on at night. The first attempt of this

kind dates from the reconstruction of the Notre Dame bridge at Paris. Since then the electric light has been made use of in the construction at the Louvre and the bridge of Kehl.

The electric light has also been employed upon the Clock Tower of the Houses of Parliament in London, as a signal light to show to members outside by its illumination that the House is still sitting. The source of electricity in this case was the dynamo-electric machine of M. Gramme.

The machine employed was driven by a two-horse-power engine at a speed of 320 revolutions per minute, and produced a light equal to 7,000 sperm candles at a cost of about one shilling per hour. The machine was placed in the basement of the building, and was connected with the optical apparatus at the top of the tower by thick copper wires, through a distance of 900 feet.

As the extinction of the light indicates the adjournment of the House, it became of paramount importance to insure the absolute continuity of the light, and as the longest carbons last only about five hours, and the House frequently sits for ten, a special apparatus had to be employed, which was designed by Mr. Conrad Cooke, under whose directions these experiments were conducted. Two Serrin regulators are carried side by side upon a miniature trolley, underneath which are two sets of copper springs, so adjusted that when one lamp is in position in the focus of the optical apparatus, its corresponding springs are in metallic contact with two studs, which are the terminals of the wires leading from the machine. The lamp is by that means thrown into the circuit and the light is established. When the carbons are nearly consumed the trolley is quickly shifted from right to left, or *vice versâ,* and the springs of the second lamp come into contact as the others are run off. The break of continuity is but momentary, but this does not affect the light, as the time is too short for the incandescence of the carbons to subside.

Other less successful attempts have been made to use it for the public illumination of large towns. It was first attempted to replace the numerous gas-lights in the squares, quays, and streets by a powerful electric-light, the rays of which were thrown by reflectors over the whole space to be illuminated. The effect was brilliant, but disastrous, and for this reason. The electric-light is distinguished by an extreme intensity, but for this very reason its

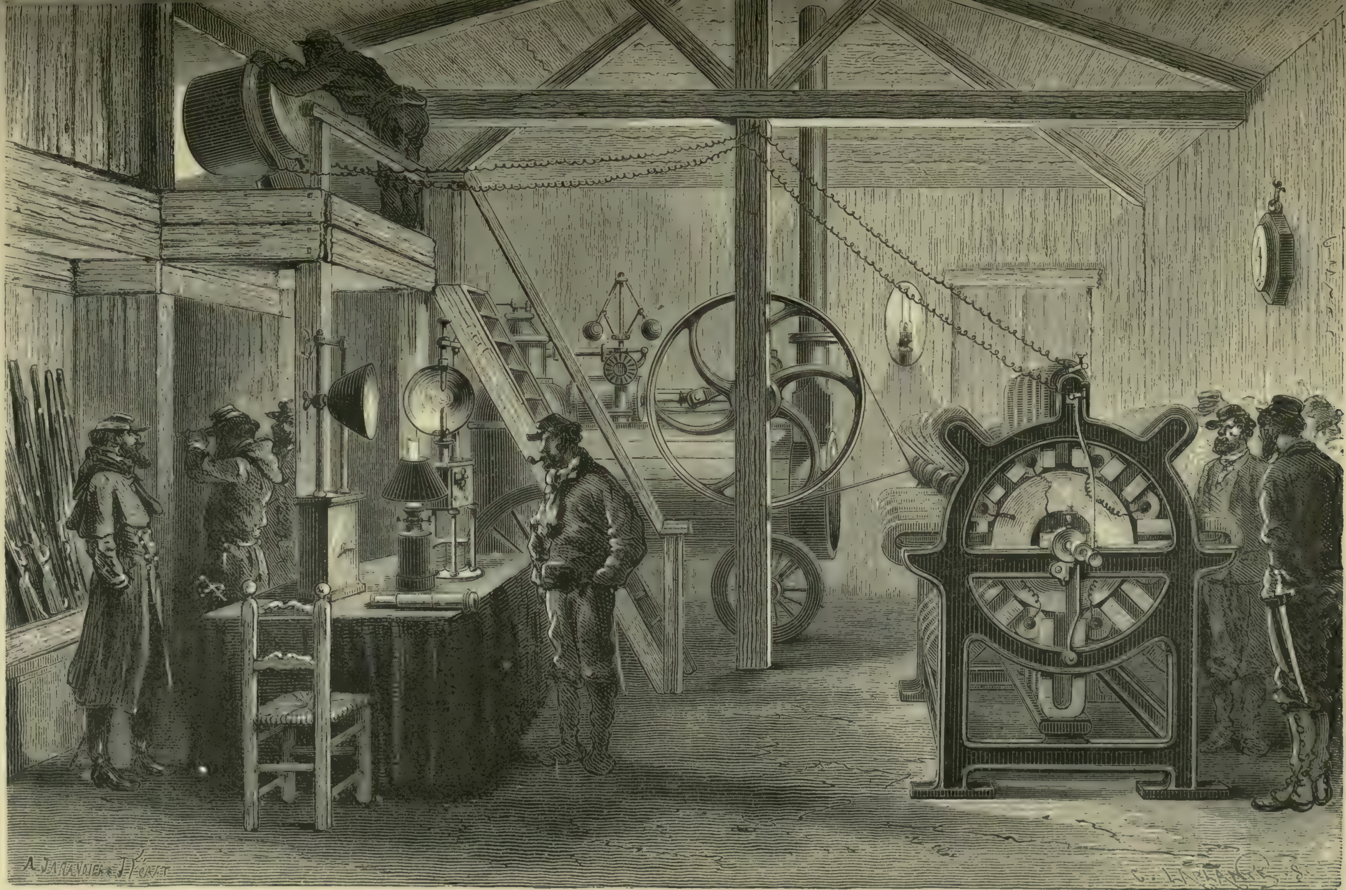


PLATE XXI.—THE ELECTRIC LIGHT DURING THE SIEGE OF PARIS.
Station at the Barrier of Montmartre (Alliance machines).

brillancy is unsupportable. On dark nights it has the same effect as lightning. Another great disadvantage arises from the circumstance of one single blaze replacing a multitude of luminous points, which results in a startling contrast between the strong light on illuminated objects and the dark and hard shadows thrown on the unilluminated parts. In a word, the light by this system is not diffused on all sides, and the attempted substitution of several lights for a single one only diminished these inconveniences without destroying them.[1]

Although, however, the electric light does not appear to be applicable to public illumination under ordinary circumstances, it may, on the contrary, be advantageously employed at fêtes.

But a more important and useful application was that made of the electric light during the siege of Paris for reconnoitring the works and operations of the enemy at night. Apparatus was fixed for this purpose on Mont Valérien and on the barrier of Montmartre. At this latter station the light was produced by an *Alliance* magneto-electric machine. A parabolic reflector, having its focus at the point where the carbon points produced the light, threw the beam of light to a distance, in a direction which might be changed at pleasure, according to the orders of the officers charged with these reconnoitrings.

Plate XXII. shows the Siemen's dynamo-electric light apparatus as arranged for Field Service, an employment which is certain to be found for it in future campaigns.

We shall conclude what we have to say upon the electric light and its applications by recalling what we have already said on its advantageous employment for microscopic projections, as well as its use in photography. In both these cases the electric light makes up for the absence of the sun. We shall also say a word on the electric lamps that have been invented for illuminating mines, and are at the same time safety lamps; the light produced in this apparatus is not the voltaic arc leaping between two carbon cones—there is no necessity in this case for so considerable an intensity.

[1] Does not this enervating action of the rays of the most refrangible part of the spectrum depend in some way on the extreme rapidity of the undulations of the ether which they produce, which agitate the retina and optic nerve with excessive energy?

The induction-spark, which, as we have seen, is produced in a

FIG. 446.—Dumas and Benoit's electric lamp for miners.

rarefied medium or in a vacuum, though giving but a feeble light, is nevertheless sufficient for the illumination of mines, and they

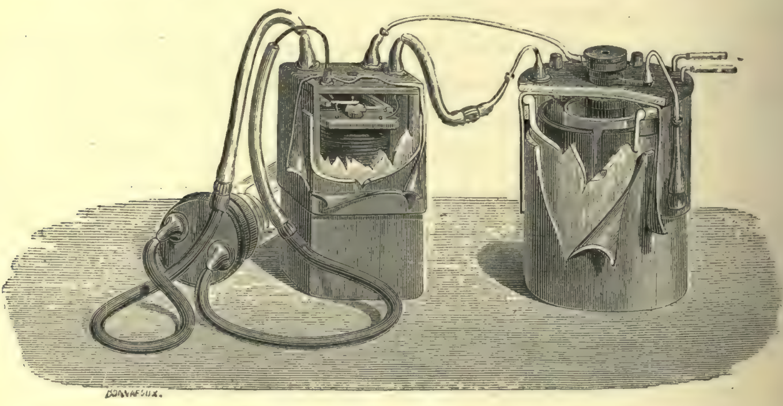


FIG. 447.—Electro-magnetic apparatus for the miner's lamp.

are thus adapted to be safety-lamps, such as that represented in

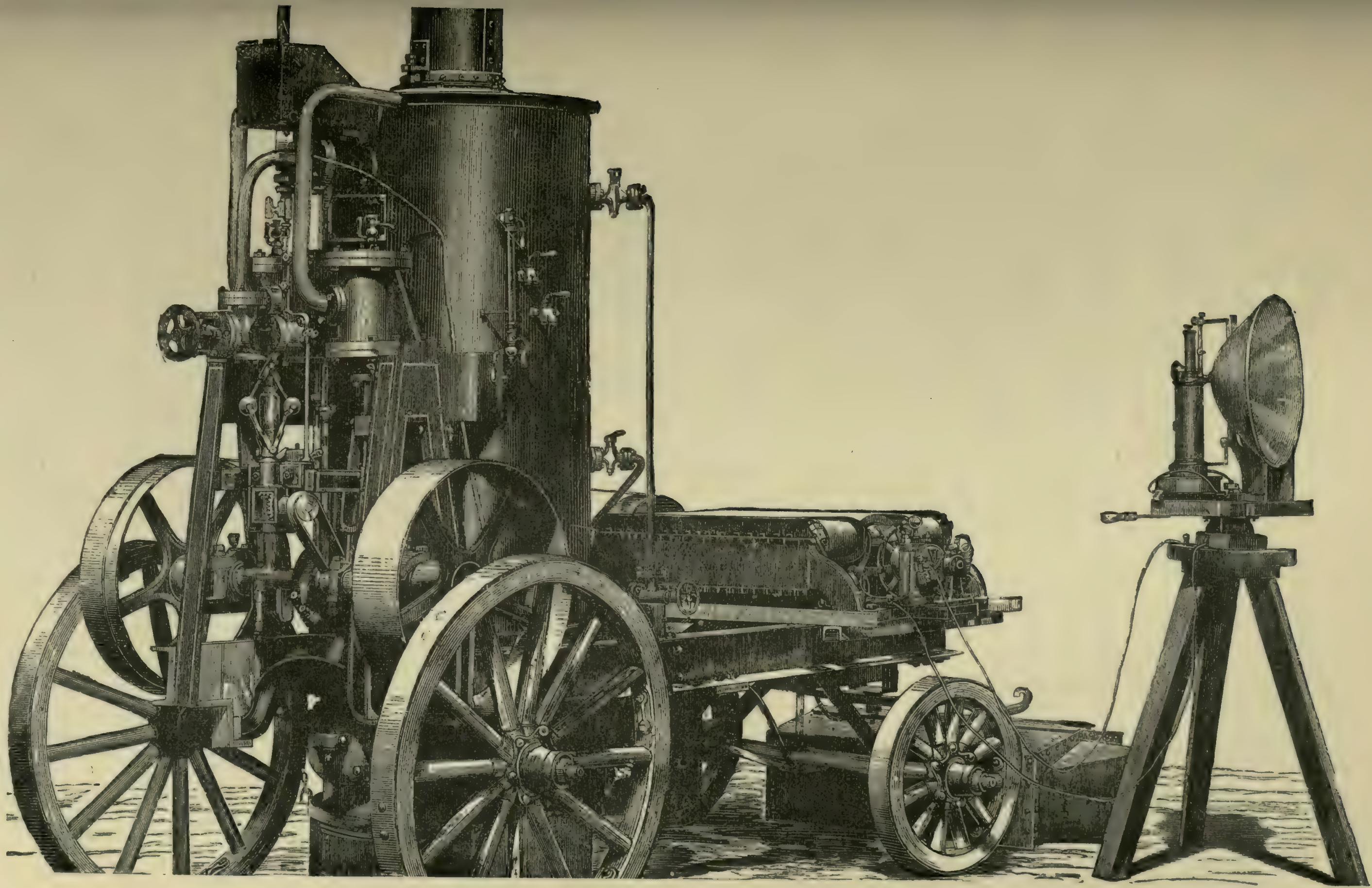


PLATE XXII.—THE SIEMEN'S LIGHT ARRANGED FOR TRAVELLING

Fig. 446. A capillary tube twisted into a spiral is placed in a glass cylinder; two platinum wires communicating with the bobbin are cemented to its two extremities, between which the successive discharges take place, as in Geisler's tubes. The lamp is attached to a box containing the induction apparatus and the battery. (Fig. 447.)

This system of illumination preserves the miners from all danger. In fact the luminous beam is produced in a vacuum without any communication with the air contained in the glass cylinder, and much less with the air of the mine, besides which, if the apparatus is broken, the entrance of the air immediately destroys the spark, and with the extinction of the light all danger of fire disappears.

§ III.—Blasting in Mines.—Torpedoes.

The blasting of chambers in mines by the old methods is often a dangerous operation, and the accidents caused by it from time to time are unhappily too serious for us not to attempt to prevent them. In order to set fire to the powder inclosed in the chambers the process was as follows:—Communication with the interior of the mine was effected by longer or shorter trains of powder placed on the surface of the ground, or by canvas tubes full of powder, technically called fuses. Then at the end of the train was placed tinder lighted at the end, outside the mine, the dimensions of this tinder being calculated so that the workmen in charge of the operation might have time to get away. It was useless to insist on the danger of too sudden a kindling; often it was the delay of the kindling that caused the accidents, especially if several mines were blasted at the same time and it was not known in which the explosion had not yet taken place; or lastly, if any trains were supposed to be gone out, when, in reality, they were not.

By making use of currents, and of the spark which is produced at the moment the circuit is closed at a distance, all danger

ought to disappear, and in fact has disappeared. Sometimes a battery and sometimes Ruhmkorff's induction coil is used for the purpose, and sometimes again induced currents from magneto-electric engines.

In the beginning of this new application of electricity the battery

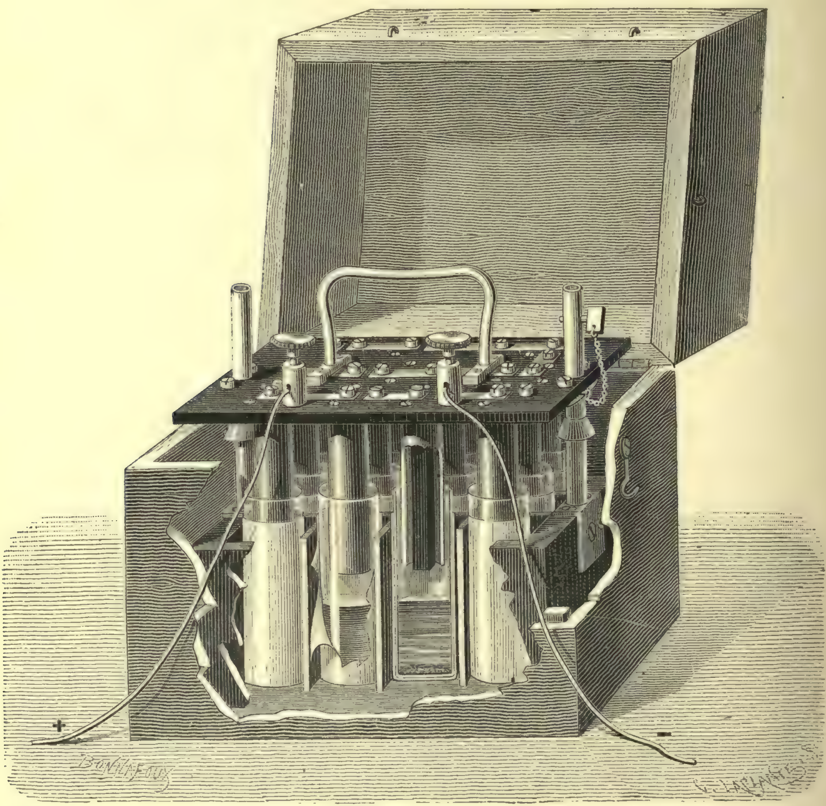


FIG 448.—Bichromate of potash battery for blasting mines.

was always used. But a powerful battery was required, and metallic conductors of a great diameter. A platinum coil embedded in the powder is brought to incandescence when the circuit is closed, and the explosion takes place; a battery composed of bichromate of potash elements is now used, inclosed in a box, and so arranged that

a very simple mechanism plunges all the zincs into the liquid at the same time. This process, which had been abandoned for those we are about to describe, has for several years past been resumed and improved.

The method of blasting by the spark from Ruhmkorff's induction coil was inaugurated at the great works at Cherbourg. This method, proposed by M. Du Montcel, was not at first successful; the heating power of the spark at the distance at which it was necessary to make the explosion was not sufficient to kindle the powder. Fortunately an English engineer, Mr. Statham, invented a fuse

FIG. 449.—Statham's fuse for exploding mines.

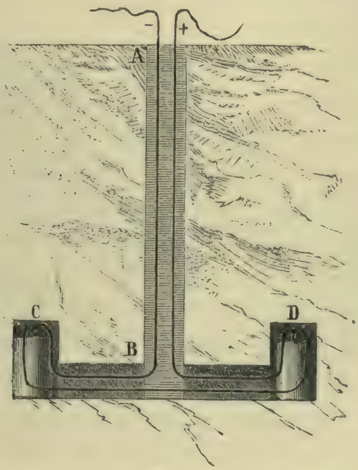


FIG. 450.—Chambers of mines.

whose inflammability is much greater than that of ordinary fuses. M. Ruhmkorff adopted the new invention, and success completely crowned his attempts. This new kind of fuse is arranged as follows:—

It consists of two pieces of red copper wire, inclosed in gutta-percha covering, the free extremities, A B, of which, after being twisted back, are introduced in a kind of vulcanized gutta-percha capsule.[1] The

[1] That is, combined with sulphur; contact with a copper wire forms a very inflammable deposit of sulphur.

two ends are brought to a distance of one or two millimetres in a kind of box, C D, which is filled which powder, after having covered the points with fulminate of mercury. "The first trial on a large scale," says M. Du Montcel, "of the application of Ruhmkorff's induction apparatus to mines was made in 1853 by the Spanish Colonel Verdu, in the workshops of M. Herkmann, a manufacturer of gutta-percha covered wire at La Villette. Experiments were made successively on lengths of wire of 400, 600, 1,000, 4,800, 5,000, 6,400, 7,600, 25,000, 26,000 metres, and the success was in every case complete, whether the circuit was composed of two wires, or the return current was carried by the earth. Only two elements of Bunsen's battery were employed in these experiments."—(*Exposé des Applications de l'Electricité*, t. iii.)

In order to explode large mines—that is to say, chambers filled with hundreds or thousands of kilogrammes of powder in several cavities in communication with each other, so as to obtain their nearly simultaneous explosion—a commutator is used, the handle of which is successively put into contact with the copper wires connected with each chamber. The explosions thus take place one after the other, but at such small intervals that they might be thought simultaneous. The employment of electricity for blasting mines is not only advantageous in the matter of security, it effects also a considerable economy (as much as 60 per cent.) on the old method of trains, by the ease with which, by its means, gigantic mechanical effects due to simultaneous explosion can be produced. In 1854, in the works for hollowing out the basin for the port of Cherbourg, it required the explosion of six mines to detach at one blow a mass of rock of 50,000 cubic metres.

The following is an exploding apparatus whose calorific power is due to the development of induced currents and of the extra magneto-electric current. Its invention is due to M. Bréguet. An electro-magnet has its poles opposite those of a powerful compound horse-shoe magnet, so arranged as to have their poles turned in opposite directions. The result of this, in the horse-shoe of the electro-magnet, is a magnetisation which is made stronger by means of a fixed armature. In front of this is a piece of soft iron, kept in contact with the armature by an antagonistic spring, and which can be separated suddenly by the rapid motion of the button

on a handle. This separation, by the resulting diminution of force in the armature of the electro-magnet, gives rise to an induced current in the wires of the coil, and also to an extra current whose intensity is added to that of the induced current. It is chiefly the power of the extra current which is used for the production of the spark, and M. Bréguet has invented an arrangement which enables this power to be used at the precise moment it has attained its maximum value.

For this purpose a spring band, in contact with a screw, does not leave it till the cessation of motion of the piece of soft iron. Now

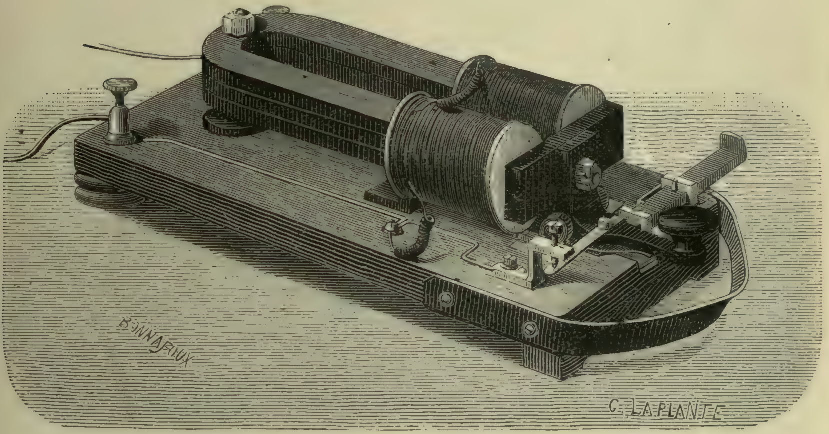


FIG. 451.—Magnetic exploder for blasting mines—Bréguet's system.

the wires of the electro-magnet end, one in the screw, and the other in the spring, so that as long as the contact lasts the circuit remains closed upon itself, and the extra current arrives at its maximum when the contact ceases, and at that moment the discharge is made across the circuit ending in the mine.

To avoid accidents when the apparatus is put into communication with several mines, a bolt stops the motion of the handle and it cannot be worked, until, all being ready, the bolt is drawn. The signal may then be given without fear.

The apparatus which we have just described may be, and in fact

is, employed not only to explode mines, but to kindle at a distance any dangerous machines or gaseous matters such as fire-damp, or even simply to light gas-jets to serve as signals. A naval officer, M. Trève, has proposed the adoption in the fleet of a nautical telegraph, to displace the night signals which are now made, as is known, by means of lanterns. These lanterns consist of lamps provided with Fresnel lenses similar to those of lighthouses, which are hoisted on one or two halliards on the most elevated part of the ship. The lighting of these lanterns and the movements necessary to put them in place occupy considerable time. M. Trève has proposed to render this kind of communication more prompt by replacing the candles of the lamps by gas.

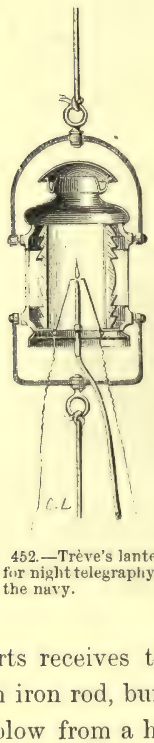


FIG. 452.—Trève's lantern for night telegraphy in the navy.

The setting fire to explosive matters at a distance by electricity, serves again for the protection of ports and the neighbourhood of fortified places. Every one has heard of those formidable engines called torpedoes, the explosion of which is so terrible that a single one (if made on purpose) could sink the greatest navy. Torpedoes played an important part in the War of Secession in the United States: a considerable number of ships owe to them their destruction. The American torpedo is arranged in the following way:—

The engine in question is a tin box of a capacity of forty-five or fifty litres, divided into two parts by a transverse partition: one of these parts receives the charge of powder, the other is the air chamber. An iron rod, buried in the powder and capped by a capsule, receives a blow from a hammer when a ship, in passing above the point where the torpedo lies submerged touches a float provided with a cord in communication with a catch upon the hammer.

The explosion is not therefore produced directly by electricity. But the advantages that might result from exploding it from a distance, according to the wish of the authorities charged with the defence were soon perceived. The Belgian ex-minister of war, General Chazal, has very ingeniously combined the employment of electricity with that of the camera obscura for the defence of the Scheldt by torpedoes.

Beneath a tent protected by earthworks, the pile or induction apparatus which produces the spark is arranged. Here all the wires which unite electrically the lines of torpedoes with the apparatus end separately, and each of them is numbered, so as to render any mistake impossible.

On a table is placed a plan of the Scheldt, where the positions

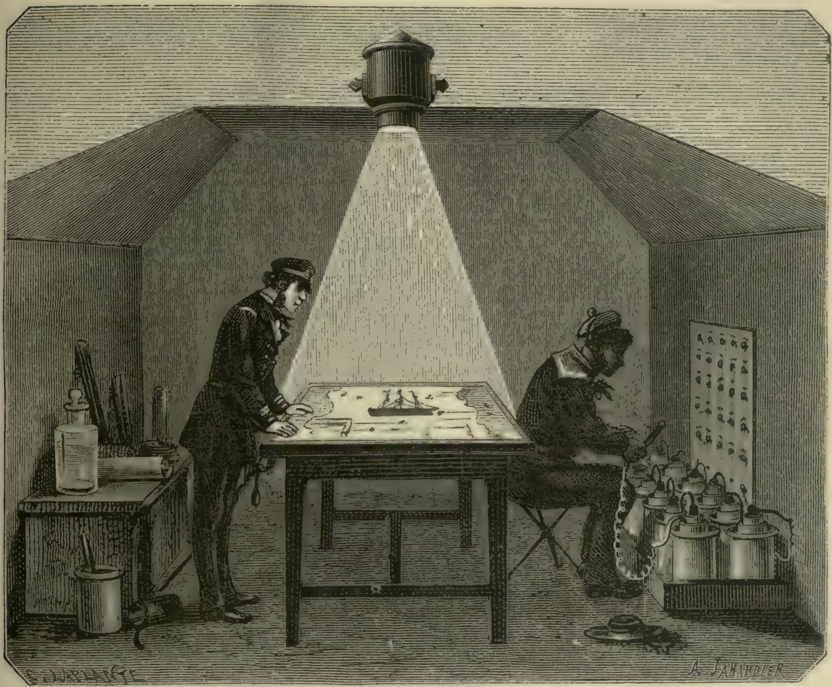


FIG. 453.—Explosion of torpedoes by electricity; General Chazal's system of defence for ports and coasts.

of the lines of torpedoes are marked, and which is simply the reproduction of the optical projection of the river by the dark-chamber apparatus placed on the top of the tent. Suppose a hostile ship should be perceived coming up the river. The officer charged with the superintendence and command can follow from minute to minute the position it occupies relatively to the lines of immersion of the torpedoes. At the opportune moment he gives the order to the marine in charge of the electrical apparatus and indicates the number of the

wire of which the circuit is to be closed. Immediately the explosion takes place. Experiments carried on for some years have been crowned, it appears, with success.

Paris, during the siege, had the neighbourhood of its ramparts and forts protected by a network of torpedoes. But as no grand assault took place against the whole city on the part of the besieging army, this system of defence, although perfectly organized, necessarily had only a preventive office.

CHAPTER IX.

ELECTRO-PLATING.

§ I.—Historical Sketch.

We have seen that electricity transmits to a distance, with a prodigious rapidity and under very varied forms, the signals made with telegraphic apparatus, sometimes limited to simple oscillatory motions of the needles of a galvanometer, sometimes writing or even printing in known characters the letters of a message, and sometimes reproducing with a surprising fidelity the fac-simile of the writing or drawing which forms the message to be sent. Telegraphy then is a mechanical application of electricity, or rather of electro-magnetism, since the principle is the reciprocal action of galvanic currents and magnets. It is by using the repulsions and attractions of electro-magnets too that electric horology, chronographs, automatic registers of physical phenomena, electric engines, and a crowd of apparatus now used in the most varied branches of art and manufactures, have been invented.

But electricity does not only produce motion, it heats bodies, and that in so energetic a manner that it melts and volatilizes metals and other refractory substances, and kindles at a distance the fuses of mines, and the protecting torpedoes of ports and coasts. The brilliant light which is given out between the two carbon points rivals in intensity even the rays of the sun. By means of a mechanism whose motion is regulated by the variations of the intensity of the current, and by the combustion itself, the light of the voltaic arc can also be used for many purposes. It pierces, too, the mists in the darkest nights, and the lighthouses which Fresnel's

genius has made such powerful helps to navigation, have been increased in brilliancy and range of light.

In order to complete this view of the application of electricity it remains to give some account of those which are based on the chemical effects of currents; that is to say, on the still mysterious phenomena which are generally regarded in science as themselves one of the generators of dynamic electricity.

Electro-plating, electro-chemistry, are the names under which these applications are generally known; applications of which science, manufactures, and art have all equally found to be profitable; one word on their common principle will suffice to justify the distinction we have just made.

Let us first call to mind the phenomena produced when a galvanic current is made to pass through a saline solution. Take, for example, a solution of sulphate of copper. So soon as the circuit is closed and the current produced, decomposition of the salt takes place; bubbles of oxygen are disengaged at the positive electrode, and copper is deposited in a metallic state upon the bar which forms the negative electrode. This phenomenon of decomposition was already known to those physicists who had at their disposal only the original voltaic piles; but on account of the irregularity of the current, and its rapid falling off, the metallic deposit was generally only a pulverulent crust, and useless for industrial purposes. Science, however, took advantage of it, and chemists were thus enabled to isolate and discover metals till then unknown. The invention of constant batteries such as Daniell's modified the phenomenon in a favourable manner. We have had occasion above to cite the discovery of the first electromotor—namely, that which Jacobi invented to navigate a vessel on the Neva. If that invention had not the success that its author expected, it was the occasion of a more fortunate discovery, whence has certainly arisen the art of electro-plating. Jacobi, who had employed a Daniell's battery for his experiment with the positive pole formed of plates of very pure and very malleable copper, was astonished to see the plates of platinum of the negative electrode covered with a rough deposit, formed of little scales of brittle copper, the inner surface of which faithfully reproduced all the inequalities of the metal on which they had formed. The illustrious physicist repeated the same experiment with variations, and obtained homogeneous metallic deposits, which, instead of

being pulverulent, had all the consistence, compactness, and ductility of the purest metals, as furnished by metallurgical operations. Moreover by replacing the copper plate of the pile by moulds of medals, or plates engraved in relief or intaglio, he obtained faithful reproductions in intaglio, or relief, of the originals. Such is the origin of electrotyping, which a clever Englishman discovered also for himself the following year. The invention soon obtained a great development, and was the starting-point of numerous artistic and industrial applications, and the subject of important improvements.

The processes which constitute electro-typing give deposits which are exact models of the objects to be reproduced without adhering to them. But it is possible also to obtain very thin deposits, which adhere to the surface of the objects and act as a protective covering without sensibly altering its contour, or its form: the processes employed in this case constitute gold-plating, silver-plating, copper-plating, &c., according as the deposited metal is gold, silver, copper, &c. Such is the difference, as far as results are concerned, between electrotyping and what is sometimes called galvanizing or electro-plating. The principle is the same, but the processes are different; indeed, as we shall see, they were discovered independently. The invention of electro-gilding goes back in fact much further than electro-typing.

In 1805, a professor of chemistry at the University of Pavia, Louis Brugnatelli, discovered a means of gilding medals, and little articles of silver, by means of a battery. He used a solution of chloride of gold in ammonia (ammonio-chloride of gold), in which he plunged the article to be gilded, and made it communicate with the negative pole by a steel or silver wire. But this invention remained unknown and unapplied. In 1840 M. de la Rive, the illustrious physicist of the Academy of Geneva, after long researches made for the purpose of relieving the working gilders from the dangers arising from the employment of mercury, succeeded in gilding brass, copper, and silver by means of the battery. The liquid he employed was a solution of chloride of gold as neutral as possible and very weak (five to ten milligrammes of gold to a centimetre cube) in a cylindrical bag made of a bladder. This diaphragm was plunged in a glass vessel containing water suitably acidulated. The article was immersed in the solution of gold. A zinc cylinder joined by a silver thread to the object to be gilded caused the production of the electric current,

which had to be very feeble. Various improvements were introduced to the process of M. de la Rive by several savants—as MM. Elsner, Bættger, Perrot, and Smee; but soon after, a new method, discovered almost simultaneously by an Englishman, Mr. Wright, and patented by Mr. Elkington (September 1840), and a Frenchman, M. de Ruolz (1841), gave to this application of electro-chemistry a fertile impulse. Electro-plating from this moment became a true industrial art in the hands of M. Chistofle, who acquired the patents of M. de Ruolz.

Without entering into the detailed history of the phases through which electro-plating has passed during thirty years, we will describe the various processes as they are now generally carried on.

§ II.—Electro-typing.

Electro-typing, viz., the art of reproducing by a homogeneous, but a non-adherent and sufficiently thick metallic deposit, the relief of any object such as medals, statues, bas-reliefs, architectural ornaments, jewellery, &c., may first be referred to.

Electro-type reproduction is performed in two different ways, according to the object in view. If an identical reproduction is required, in which the reliefs and intaglios of the copy shall be the same as those of the model, a mould must first be made whose intaglios correspond to the reliefs of the model, and *vice versâ.* The ordinary processes of moulding are then employed; but it is plain that the mould or cast might be first obtained by electro-typing, and then by a second operation made on the counterpart, the object would be reproduced. The first of these operations only is required if a reproduction in intaglio of the reliefs of the model is to be made.

In any case, the surface of the mould on which the current is to deposit the desired metal must be a good conductor of electricity; and this is the case when the mould is metallic. If however, as often happens in practice, the mould is of wax, sulphur, plaster, or even of gelatine or gutta-percha, the surface must first be metallized. This is accomplished in several ways. The simplest plan is to cover the mould with a uniform thin coat of powdered plumbago by means of a pencil or brush.

This method of rendering the mould a good conductor is due to

M. Jacobi. A solution of nitrate of silver in alcohol may also be used. The surface of the mould moistened with this is exposed to a stream of hydrosulphuric acid, when an extremely thin black layer of sulphide of silver is formed, which is an excellent conductor. This second method is chiefly employed in the reproduction of delicate objects, as flowers and fruits, or objects in glass or crystal.

The mould being obtained, and made ready to receive the metallic deposit, the bath and other electro-plating apparatus must be prepared. What is called the *simple apparatus* is just the bath itself, which forms, in truth, a constant cell, like Daniell's. Suppose we want to reproduce an object in copper, which is the metal most frequently

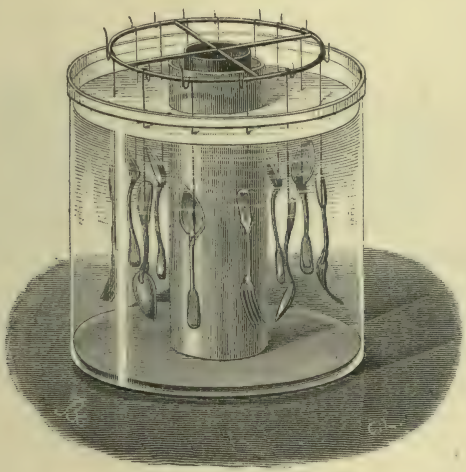


FIG. 454.—Simple apparatus for electro-plating.

employed, we place in a tub or glass vessel a solution of sulphate of copper.

In the centre of the tub is placed a porous vessel filled with water acidulated with sulphuric acid, and into this is plunged a plate or cylinder of zinc, which forms the negative pole of the battery. To this pole is suspended the mould of the object to be reproduced, by means of a metallic wire which wraps it round so as to be in contact with the conducting layer (plumbago or sulphate of silver). Fig. 454 shows the arrangement of the apparatus, which will serve equally well for gold or silver electro-plating. In this case the nature of the bath is altered, as we shall soon see.

When the current is established, the sulphate of copper is decomposed and a deposit of the metal is formed on the surface of the mould. But in proportion as this deposit is formed, the bath is impoverished by the same amount, becoming more and more acid, and the deposited metal loses its plastic properties and its coherence, unless the solution is maintained in its normal state of saturation by crystals of sulphate of copper placed in a bag within the bath.

What is called in electro-plating a compound apparatus only differs from the simple apparatus in having the battery separate from the bath; to prevent the impoverishment of the bath a sheet of copper is suspended in it in communication with the positive pole of the battery, while the mould is metallically united to the negative pole.

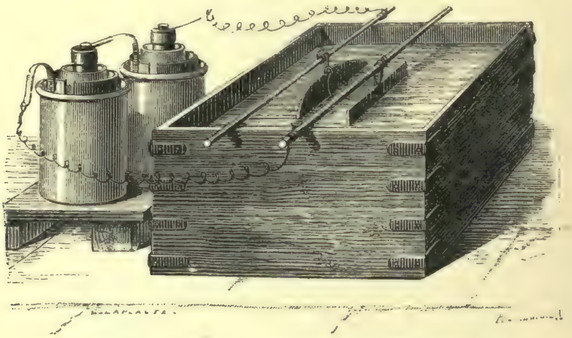


FIG. 455.—Compound apparatus for electro-plating.

This sheet constantly gives up to the solution the quantity of copper that has been deposited, so that the concentration of the bath remains constant. Jacobi, to whom this latter arrangement is due, has called the sheet of copper in the compound apparatus, the Soluble Electrode.

We may now enter into certain details concerning the different industrial and artistic applications of electro-typing.

The processes just described are applicable in that form to the reproduction of medals, seals, and other objects of small dimensions engraved on one side only. They are used for the reproduction of wood, steel, and copper engravings, which would rapidly wear out and be spoiled, if submitted to direct working off, but which electro-typing enables us to preserve indefinitely.

A wood engraving gives at a maximum ten thousand copies. But

as many stereotype plates for printing from as we may wish may be reproduced in the following way. The surface of the wood is first metallized by plumbago, and then an impression is taken with gelatine or gutta-percha. The mould thus obtained and metallized is submitted to the electro-plating process, and a layer of copper is deposited on it, which reproduces with the greatest fidelity the finest marks of the engraving at the end of a certain time, generally not more than five hours. The thickness of the metal covering is about $\frac{1}{20}$th of a millimetre. This is not sufficient to offer proper resistance to the action of the printing press, but it is strengthened by pouring

FIG. 456.—Reproduction of a Medal by electro-typing: intaglio Mould and Meda reproduced in relief.

over the other side a mixture of lead and antimony (type metal). It is then planed, and mounted on wood, and the stereotype plate thus obtained is ready for working off. It can then produce without spoiling or alteration an impression of eighty thousand examples As to the wood engraving, it remains absolutely intact, and can furnish an indefinite number of similar stereotype plates.

An analogous process gives a reproduction of copper or steel engravings. Ordinarily the cast is obtained by electro-typing, and this mould is used to reproduce the original plate. A precaution however must be taken, in order to avoid adhesion, and this is done by expos-

ing the plate, before putting it into the bath, to the vapour of iodine. In this way for example the postage-stamps are printed. Two or three hundred moulds of the original engraving are joined together, and plates are thus procured from which sheets may be obtained containing the same number of stamps. To prevent imitation, which by impressions on stone might easily be made, the paper on which the stamps are printed is treated with a white safety ink, which would be transferred to the lithographic stone with the drawing, and the impression obtained would be nothing more than a uniform blot covering the whole sheet.

The stereotype-plates employed in printing the Bank of England notes were made by Smee by electro-plating. To give an idea of the durability of the stereotype plates we quote the following words from a memoir by that physicist, in which he gives an account of the processes employed in this reproduction. "The electro-copper," he says, is so durable, that we can scarcely assign a limit at which it becomes useless." And for the *Times* newspaper we are told that a mould of this kind has already furnished an impression of twenty millions without being completely worn out. Up to the present time, the limit of the durability of the electrotypes for printing the Bank notes has not been reached, and there have been already printed from them a million notes without any very sensible effect.

In France, M. Hulot employed electro-typing for the reproduction and printing of the Bank notes issued in 1848, and since then for the figures on playing cards.

If electro-typing renders signal service in the impression of engravings of various kinds, it is no less useful for the correction of engraved plates; for example, in the introduction of new details in geographical and topographical maps. These modifications are indispensable in great works like that of the Ordnance Survey maps. Alterations of roads, the addition of new roads, of railways, canals, industrial works, &c., were formerly only possible by processes of retouching, and recutting, which risked the damaging of the plates. M. Georges has invented a method of correction by which these great disadvantages are avoided. The parts to be corrected are removed by a scraper, and a deposit of copper on the spot is made by electro-plating, the necessary precautions being taken. It is then planed carefully, and a proof is taken in which the parts to be altered come out blank. The artists

then trace the new lines, which are transferred to the plate and then delivered to the engraver.

It is well known that for printing plates by chromography, the various colours must be rigorously fitted in their right places. Electrotyping enables us to fit them perfectly in plates of this kind. The National Press of France has thus been enabled to print many maps in colours, and particularly the great geological Map of France, which is itself based on the Staff Maps for all that regards the topographical part.

But electro-typing not only reproduces plates identical with engraved ones, but it is applicable to direct engraving, such as copper-plates and etching, only in this case it is not done by a metallic deposit, and the plate on which the drawing to be reproduced is drawn, instead of being placed in the bath as the negative pole, corresponds to the soluble anode. In fact, its surface being covered by a thin layer of insulating varnish, and the drawing made by a fine point having exposed the metal beneath, the latter is attacked by the electrolytic action, and it is eaten into in the same way as in ordinary etching, and the engraving is executed without the operator being exposed to the injurious action of nitrous fumes.

The processes of Duclot, Gillot, and Gamier, for engraving in relief on copper or zinc, are also partly based on electrolysis; but the details of the operations necessary for these processes are too minute to be reproduced here,—we should be drawn, besides, beyond our subject.

We next come to the application of electro-plating to the reproduction of objects in the round such for instance as busts, statues, vases, capitals, and other architectural ornaments. The principle is just the same, only the reproduction of objects of large size offered at first certain difficulties that have been happily surmounted. The object is to avoid all inequalities of thickness in the deposits on different parts of the mould, and yet to obtain a thickness all over which shall give a sufficient solidity to the object of art reproduced. Suppose a mould of a statue, the parts of which come together so as to leave a hollow which was occupied by the model before the moulding. The question is how to obtain, all over the interior, an equal and regular deposit of copper. At first a soluble anode was placed inside the mould, but the rapid solution of this

anode only gave an uneven deposit of insufficient thickness. M. Lenoir proposed to employ an insoluble anode, made of platinum wires twisted through all parts of the inside without touching it. Crystals of sulphate of copper, enclosed in a gutta-percha pocket pierced with holes, furnished the copper necessary for the renewal of the solution, as the deposit thickened, but this was a costly method

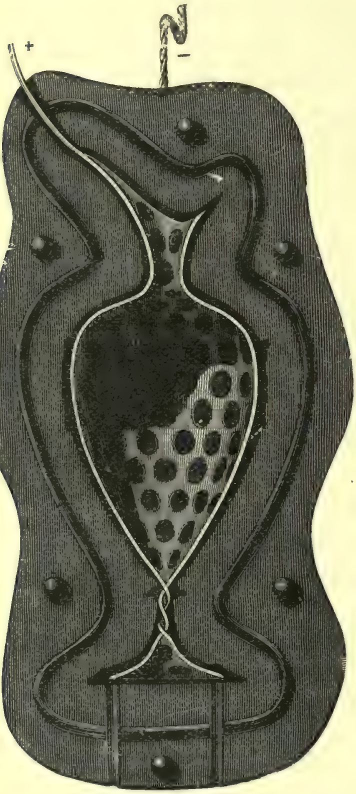


FIG. 457.—Arrangement of the mould or electrotyping objects in the round.

FIG. 458.—A vase reproduced in electrotype.

and only applicable to small objects. M. Planté replaced the platinum by lead; a nucleus of lead pierced with holes is introduced into the mould, roughly reproducing its form, only a little smaller, so as to leave between the nucleus and the side a suitable interval.

Fig. 457 shows how this nucleus of lead is arranged in one of the halves of the mould which served for the electrotypic reproduction of

the vase in Fig. 458. By the process of which we have just given an outline, the modelling of the most beautiful, as well as the largest, statuary works has become possible. Statues two metres high and even up to 4½ metres, for the new opera hall, have been moulded by electricity with a perfection not to be surpassed by the ancient art of casting. A statue of 9 metres weighing 3500 kilograms has been made in the same way. The thickness of the copper is not less than 4½ mm., but it took no less than two months and a half to bring this operation to a close. These remarkable works have been executed by a large manufacturing house in France, Messrs. Christofle and Co. M. Oudry has reproduced in copper by electro-typing, the bas-reliefs composing the column of Trajan; these bas-reliefs, 600 in number, have each on an average an area of a square metre; so we see by the importance of this work that the art of electro-typing, so remarkable for the fidelity and perfection of its productions, has become in the hands of inventors and manufacturers, an industry of truly great importance.

§ III.—GALVANIZING.—GOLD AND SILVER PLATING.

The principle on which gold and silver plating depends, and in general the deposit of a metal in a thin adherent layer on the surface of an object, is the same as that of electro-typing. It is always the electrolytic property of a galvanic current, which in passing through a solution of gold or silver, &c., decomposes it, and sets free the metal at the negative pole.

But, though the principle is known, there still remain practical difficulties to be overcome; the conditions of adhesion of the deposit must be determined, the best composition of the bath discovered, and the best method of preparation of the objects to be plated. We have seen that the first really applicable processes of gold and silver plating are due to Messrs. Wright and De Ruolz.

The apparatus employed, whether simple or compound, are the same as we have described under electro-typing. The preparation of the object consists principally in cleaning the surface, which ought to be perfectly cleared from every foreign substance. If the object is in bronze it must be brought to a red heat. If in brass it must be washed with a concentrated solution of soda, but there always remains

a thin layer of oxide which must be got rid of by pickling, an operation which is performed by dipping the object in a basin of acid; lastly, if the object to be gilded or silvered is of iron, steel, zinc, or aluminium, it must be previously covered by electro-plating with a thin coat of copper, without which the gold or silver deposited on its surface will not adhere.

And now as to the preparation of the bath. For gilding, a solution of cyanide of gold in an excess of cyanide of potassium is used, and for silvering the composition is similar—namely, a solution of cyanide of silver in an excess of cyanide of potassium. It is advisable to keep the temperature of the bath, during the operation, above the ordinary—generally at 70° C., since when formed in the cold the colour of the deposit is not so good. The positive pole is formed by

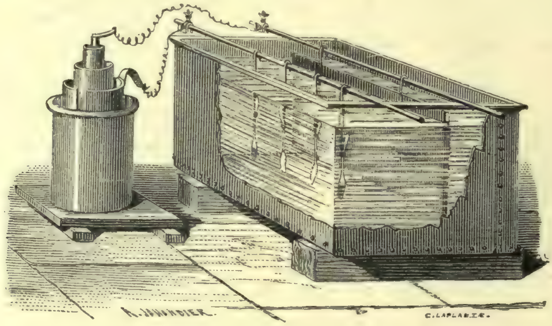


FIG. 459.—Compound apparatus for electro-silvering.

a plate of gold or silver by which the current enters the solution, and which acts as a soluble anode. The object to be silvered or gilded forms the negative pole. When the electrolytic action commences the cyanide of gold is decomposed, the gold is set free at the negative pole, where it spreads by degrees all over the surface of the object; but the cyanogen, passing to the positive pole, combines there with the gold, and as much cyanide of gold is formed again as the current decomposes. The strength of the solution is unchanged, which is an essential condition of the operation. The phenenoma are exactly similar in the silver bath.

Figs. 459 and 460 show how the apparatus for gold and silver plating are arranged. The objects are suspended in it by copper rods

on a metal sash which communicates with the negative pole of the electric battery. Another sash, insulated from the first, carries rods to which are hung the sheets of gold or silver forming the soluble anodes.

The force of the current must be regulated so as to give a perfectly adherent deposit. The thickness of the layer deposited depends in other respects on the duration of the operation. By weighing the cleaned objects before putting them into the bath and weighing again after they come out, the exact weight of the precious metal deposited

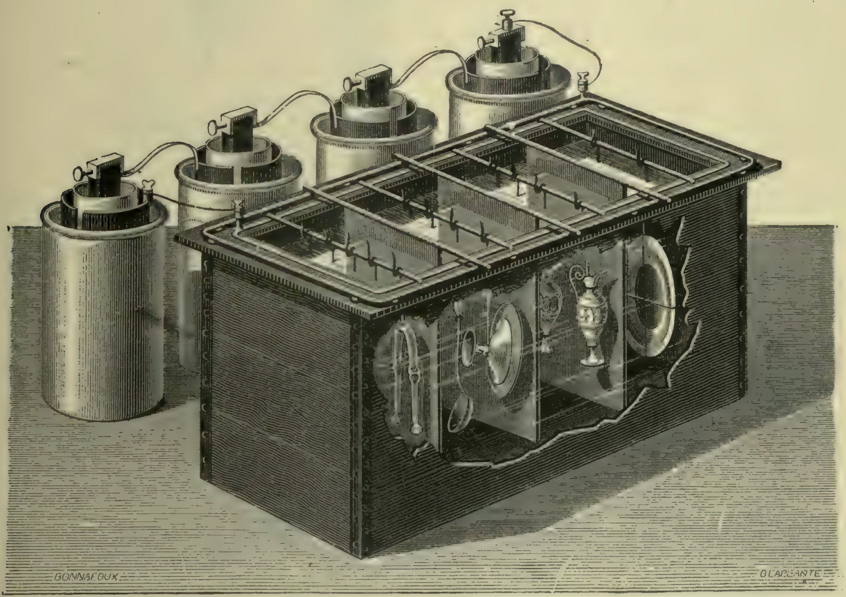


FIG. 460.—Compound apparatus for gold and silver electro-plating.

can be ascertained, and thus the thickness of the gilding and silvering be determined.

An apparatus may even be employed which automatically regulates the continuance of the operation when it is required to cover the objects with a determinate weight of the precious metal, gold or silver. This apparatus, invented by Roseleur, is simply a balance arranged as indicated in Fig. 461.

On the left is seen the apparatus placed beneath the beam, so that

the objects to be silvered or gilded may be supported by it when they are plunged in the bath. A horizontal rod fixed to the column of the balance carries on one side the soluble anode which is held in the bath and communicates on the other side with the positive pole of the battery. The other side of the beam carries a double

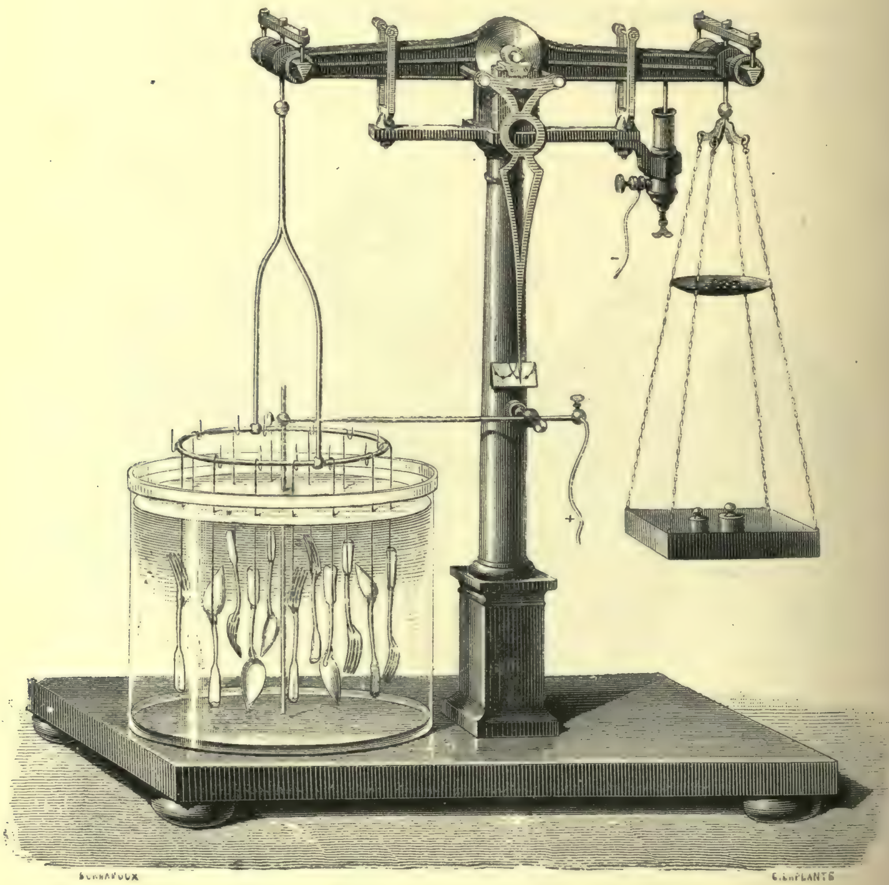


FIG. 461.—Roseleur's balance for gold and silver electro-plating.

scale-pan; in the upper is placed a counterpoise which produces equilibrium and keeps the beam horizontal. In this position no current passes, since the rods carrying the objects which form the negative pole do not communicate with the battery. But if in the second pan of the balance are placed weights equal to the amount

of precious metal to be deposited on the submerged objects, equilibrium is broken, and the beam dips on the right; a metal rod with which it is provided dips into a cup filled with mercury connected with the negative pole of the battery, and then the circuit is closed and the operation commences.

The operation continues without supervision so long as the deposit does not exceed the determined weight, but as soon as this limit is passed, equilibrium is re-established, contact ceases, and the current is interrupted.

We need not enter into the details of the purely technical operations which follow the deposit of the layer of gold or silver on the objects, after they have been taken from the bath. We will only mention that the dull colour of this layer is made brilliant by scratch-brushing and burnishing; that is to say, by rubbing the parts which ought to be polished, by a rapidly rotating brass-fibred brush, and then hand-rubbing by the workman by means of hard particles of stone or steel mounted on rubbers.

Silver is made to shine directly by placing in the bath, during the operation, a very small quantity of sulphide of silver. This process was invented by M. Planté.

The electro-chemical method of silvering and gilding is now applied on a very large scale all over the world. By its means has been introduced into houses of very modest pretensions, the luxuries of the well-to-do.

The following extract from the *Grandes Usines* by M. Turgan will show the importance of this industry in France alone:—"A few figures taken at random, will give an idea of the importance acquired by electro-metallurgy in the house of Messrs. Christofle since the expiration of Elkington's patents. In 1865 they silvered 5,600,000 objects, which has withdrawn from circulation 33,600 kilogrammes of silver, worth 6,700,000 francs; an equal quantity of objects executed in solid silver would have withdrawn from circulation a million kilogrammes of silver; that is to say, more than 200 millions of francs; 33,600 kilogrammes of silver of the thickness adopted in plating, that is three grammes on each centimetre square, would cover an area of 112,000 square metres."

Gold and silver plating are now applied in a variety of circum-

stances, as for the chased ornaments used to adorn furniture. The variety of effects which may be obtained by what are called *reserves*—that is, by gilding certain parts, silvering others, here employing green gold, and there red gold—has given to the ornamentation of furniture

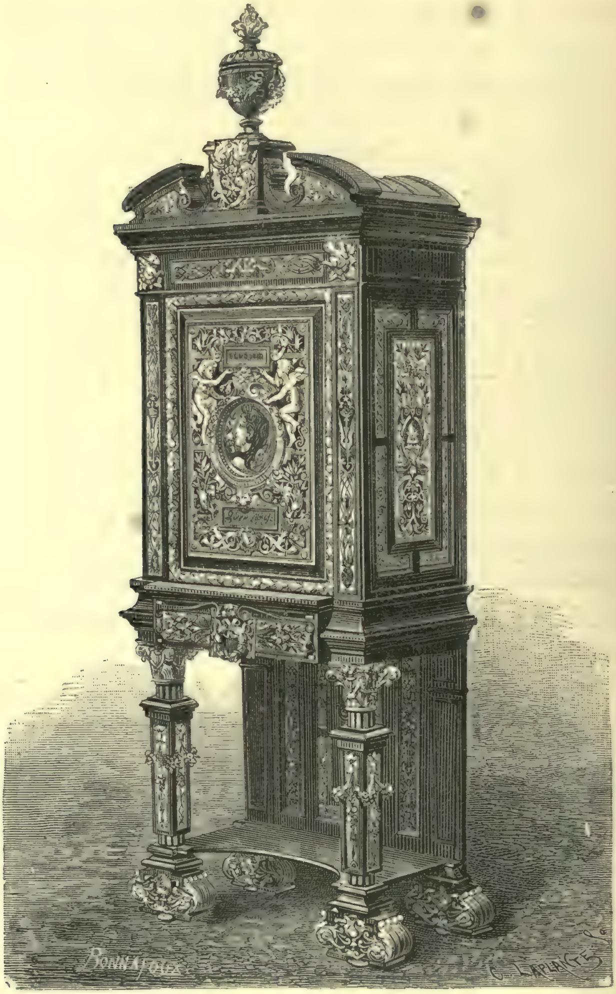


FIG. 462.—Artistic furniture ornamented with incrustations obtained by electro-plating.

a luxurious richness truly remarkable. As the reserves can be hollowed as deep as may be wished and filled with metals of all sorts, this richness does not exclude solidity.

Gold and silver are not the only metals which are applied in thin layers by electricity. Deposits can now be obtained of platinum, tin, iron, and nickel by employing suitable solutions of these metals. For platinum, a solution of the double phosphate of platinum and soda is used. Objects of iron are plated with tin in a bath of pyrophosphate of soda and protochloride of tin. Lead and zinc can be galvanized in the same way.

FIG. 463.—Workshop or copper electro-plating in Oudry's manufactory.

An important application of electro-plating consists in covering copper-plates with iron. The surface of the engravings thus acquire a durability which preserves them from all alteration during printing. When the thin coating of iron thus deposited is worn out and the red tint of the copper-plate beneath is visible, a fresh coating of iron prevents any further alteration.

Another recent industry, based on the same processes, has acquired in the hands of its inventor, M. Oudry, considerable development. It consists in covering objects of great dimensions, such as vases, statues, candelabra, &c., with copper. Among the practical difficulties to be

overcome, we will only mention here what concerns the fundamental operation; that is to say, the adhesion of the copper deposits on object whose dimensions prevent their being prepared and cleaned with the minute care of the silversmith. It was found absolutely insufficient to simply cover the surface with a layer of plumbago. The acidity of the baths attacked the metallic surfaces long before the deposit had attained the suitable thickness; M. Oudry therefore covers them first with an insulating coating unattackable by acids, applying it with a pencil after cleaning, and touching up with a file and scraper those parts of the ornaments that require it. This coating, chiefly formed of benzine, is left to dry, and then the object is plumbagoed on the outside and covered with an earthy non-conducting paste wherever the copper is not to be applied. It is then plunged into one of the vessels, or great tubs that form the baths (Fig. 463.) At the end of five or six days, the thickness of the deposit reaches a millimetre, and the operation is terminated. All that is left is to give the copper the appearance of bronze, which is done by rubbing the surface with a brush soaked in a solution of ammonio-acetate of copper.

The lamps of Paris, the monumental fountains of the Place Louvois and the Place de la Concorde, the outer gates of the New Opera, and several metallic architectural ornaments, have been coppered by this process, by which means beautiful and durable objects are substituted for the old iron castings which could not be preserved, even by painting, from rust and destruction. The electro-metallurgic industry, by the services of all sorts it can render to other industries, has undoubtedly a great future before it.

CHAPTER X.

VARIOUS APPLICATIONS OF ELECTRICITY.

§ I.—MEDICAL ELECTRICITY.

HAVE we given the description or even exhausted the list of all the applications of electricity? Not by a long way; although we have restricted ourselves to the most important, and those which have been most generally adopted. Our object, it must be remembered, was chiefly to place in relief the physico-electric phenomena of various kinds and the laws of their manifestation.

We cannot however conclude this book without mentioning a certain number of other scientific applications which appear capable of great development, such as the employment of electricity in medicine, and the registering apparatus for continuous meteorological observations.

It is no part of our business, it will be understood, to estimate the therapeutic or medical value of electricity; what is incontestable is that this agent produces physiological effects, which for a long time physicians have tried to make use of in medicine. At first the discharges of statical electricity from a Leyden jar were used, but it is chiefly since the discoveries of Galvani and Volta that the action of electric currents has been studied, and that a serious application of them to the treatment of various diseases has been made.

The electro-medical apparatus are sometimes batteries of a particular construction, sometimes induction coils so arranged in general as to allow of the employment of induced currents of either kind, according to the case of the patient.

Of these batteries, Pulvermacher's chain is the most frequently

adopted. Figs. 464 and 465 show how this battery is made and how it is used. Each element is composed of a cylinder of wood whose surface is hollowed by helicoid grooves. Two metallic wires, one of copper and the other of zinc, are rolled round these grooves without touching each other and their ends are united, each to each—the zinc with the next copper, and so on. The form of the whole is a sort of chain ending in two armatures which the patient holds in his hand, as shown in Fig. 465.

In using Pulvermacher's chain, it is plunged in a vessel containing

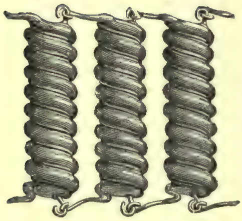


FIG 464.—Elements of Pulvermacher's battery or chain.

FIG. 465.—Pulvermacher's galvanic chain in use.

weak vinegar and water; the wood imbibes the liquid, and the chemical action of the acid on the zinc produces the current the circuit of which is completed by the arms and body of the experimenter

When shocks are to be obtained the current must be interrupted. An ingenious arrangement allows of successive interruptions. One of the armatures contains, in the inside, some clockwork which turns a wheel, one tooth of which at each revolution presses on a spring The contact of the battery with the sides of the armature then ceases and the current is interrupted. The rapidity of the interruptions

may also be regulated so as to separate the shocks by a greater or less interval.

The electro-medical apparatus founded on induction are not distinct from each other in their effects; but they may be classed as M. le Roux[1] has classed them in two categories, according to the nature of the primitive force they call into action. In the first we have those apparatus in which mechanical force is used to produce an induced current which is made to act again by induction on its own circuit, or on a neighbouring one. These apparatus are founded on the relative motion of a circuit and a magnet, and are called magneto-electric. Those apparatus in which an electro-chemical agency is employed to produce the current which

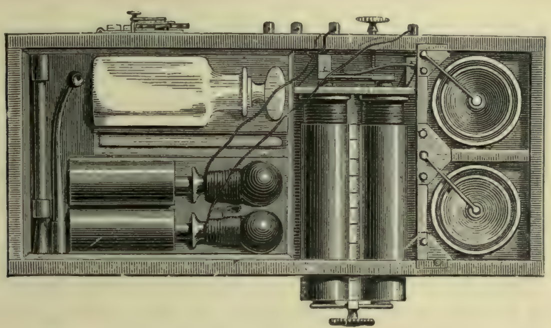


FIG. 466.—Ruhmkorff's electro-medical induction apparatus.

induces in its own circuit or another neighbouring one, form the second class which M. le Roux calls rheo-electric machines. Pixi's and Clarke's machines, described in the *Forces of Nature*, belong to the first class, and Ruhmkorff's coil to the second. In Fig. 466 we have a portable apparatus of the latter kind, due to the same inventor, which is principally used in the better class of practice.

The generating battery for the electricity is formed of two sulphate of mercury elements, seen on the right of the figure. The current is thrown into a double bobbin, and thence passes by the rheophores to two armatures, which the experimenter takes in his two hands. The interruptions of the current are produced by Neef's contact-breaker

[1] *De l'Induction et des Appareils Électro-Médicaux.*

or trembler. Lastly, the regulation of the energy of the current, and thence of the shocks, is made in the following manner:—

Each bobbin is wrapped in a covering of copper, which may be moved by a screw on the outside so as to increase or diminish at pleasure the length of the parts of the coil that are covered by this kind of muff. Induced currents are developed in the copper outside the bobbins, and since these currents are in an opposite direction to those traversing the wires of the coil, they partly neutralize each other. The experiments may then be commenced with very weak currents at first, then stronger by degrees, up to the maximum of energy, which is when the coils are entirely uncovered.

Drs. Duchenne (of Boulogne), Tripier, and several manufacturers, Messrs. Gaiffe, Trouvé, Siemens and Halske, &c., have invented electro-medical apparatus, into the description of which it would be too long to enter, as our present object is simply to give an idea of this special application of electricity.

§ II.—Electricity applied to Meteorological Observations.

Meteorology is a science which in many respects is still in its infancy,—a statement which will not appear astonishing to those who take account of the infinite complexity of the phenomena it purposes to study. The elements of these phenomena are manifold; the atmospheric pressure, the temperature of layers of the air at different heights, the temperatures of the soil and of the waters, hygrometry, the force and direction of the winds, the amount of rainfall, are so many facts which must be collected at as large a number of points of the earth's surface as possible, and which require of observers, in order to register all their variations, most laborious and painful assiduity. Those too who devote themselves to this task are generally obliged to confine their observations to fixed hours of the day and night, whence result many inevitable but deplorable gaps.

Attempts have been made for a long time to remedy this insufficiency of the means of observation, by inventing instruments to leave automatic traces of their indications, and thus to dispense with the immediate or direct intervention of the observer. Maximum and minimum thermometers are examples of this sort of instrument, but

they can only give single and isolated indications of elements; they in no sense solve the important problem of a continuous registration, or one of a very short period, which should give, for example, the curve of the variations of the temperature.

The idea of substituting automatic registering instruments for ordinary ones is not new. In 1782, Magellan invented a *perpetual meteorograph;* but it does not appear to have been used in practice. The principle of that apparatus was purely mechanical; that is to say, it derived from the movement itself that was caused by the variations of the elements, the force required for registering the indications. Many registering apparatus have been and still are founded on this principle, which have the merit of simplicity and economy, but which unhappily fail through insufficiency on account of the smallness of the force thus relied upon.

Another system consists in employing photography; that is to say, in producing on sensitive paper the image of the level of the mercurial columns of the barometer, thermometer, &c., enlarged by suitable optical apparatus. This system is naturally more costly than the mechanical one, especially as it is necessary to use clockwork to give a continuous motion to the band of paper on which the photographic records are made.

Lastly, there is a third system which employs electricity as the registering agent. Telegraphic apparatus, especially the writing and printing systems, enable us to conceive in what way the electro-magnetic currents are employed for registering meteorological indications. For example, the index of the instruments is provided with needles which pierce an endless band of paper whenever they are set in motion by the armatures of the electro-magnets; this happens whenever there is a closing or interruption of the electric circuit. A clock regulates the periodicity of these makings and breakings of contact, at the same time that its wheelwork causes the paper on which the registry is made to move forward.

We may cite some of the electro-magnetic registering apparatus employed in meteorological observations.

The first *anemograph* constructed in France was invented by M. du Montcel, afterwards modified by M. Salleron, and finally introduced by P. Secchi in the great meteorographic machine which he exhibited in the Champ de Mars in 1867.

The anemometer proper is formed of a vane for giving the direction of the wind, and a Waltmann's windlass to indicate the velocity. An azimuthal commutator, divided into eight sectors insulated from each other, is in connection by eight wires ending in the eight sectors on one side with one pole of the battery, on the other with the receiving apparatus. Upon this commutator a piston rubber constantly presses, which is directed along the axis of the vane, and constantly establishes an intimate metallic contact between that axis and the sectors. The axis being also in communication with the other pole of the battery, it follows that the circuit is always closed across the sector on which the rubber presses; that is to say, precisely in the direction of the wind. An electric communication of the same kind is arranged between the windlass, the battery, and the indicating apparatus. The latter is a cylinder moved uniformly by clockwork, so as to turn once round in twelve hours and to advance along its axis by a definite quantity, say two millimetres at each revolution. Eight electro-magnets, whose armatures are fitted with pencils, are arranged facing the cylinder, and every time the circuit of any one of them is closed, the corresponding pencil traces a mark on the cylinder, against the surface of which the movement of the armature presses it, the length of which mark indicates the duration of the wind at the same time as its direction.

The number of revolutions accomplished by the windlass is indicated in a similar fashion, and hence the velocity of the wind is regularly registered.

Space fails us to describe with the necessary details, the barometrographs, thermometrographs, and other registering meteorological instruments, whose construction is based on the intervention of electricity. It is sufficient here to have given a general idea of this application, and we shall conclude by insisting on the importance that this method of observation cannot fail to have for the progress of the science. Various systems are now followed in the principal meteorological observations at Kew, Greenwich, Brussels, Rome, Berne, and Paris. When stations of this kind shall be distributed over all the globe, on continents and islands, and a series of exact observations can be made with the necessary care and continued through long years, we shall be able to establish formulæ of greater and greater rigour to represent the laws of the movements of the atmosphere

and the other phenomena of which the aërial covering of the globe is the scene.

We are already able to represent certain facts in a general way and to mark the variations of some meteorological elements according

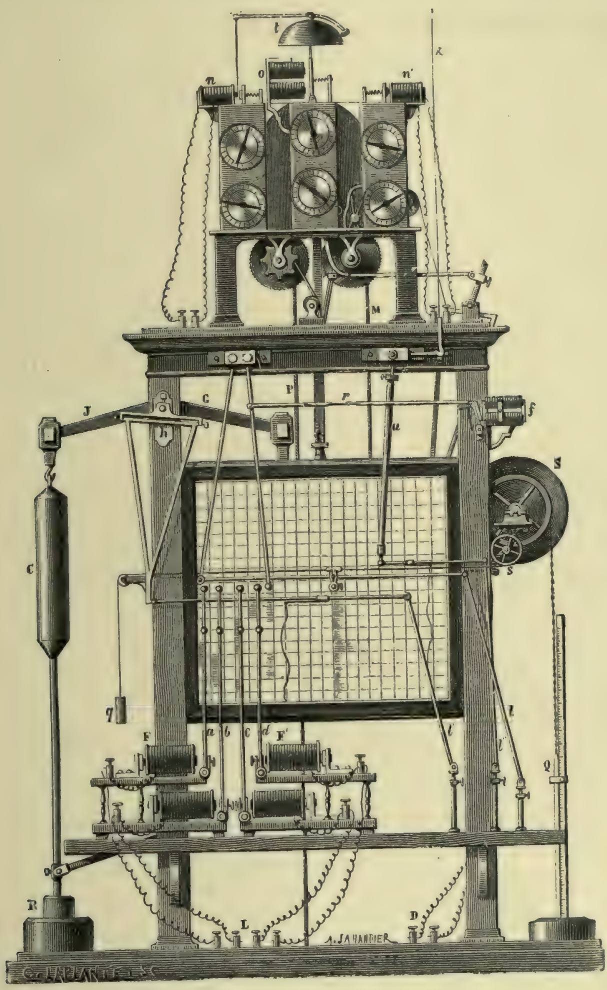


FIG. 467.—Secchi's meteorograph.

to the localities, such as the annual isothermal lines and those of the winter and summer seasons. The name *isothermal* is given to the curve marking the localities where the mean temperature throughout

the year is the same; the *isotheral* to that of points where the mean temperature of the hottest months is the same; and the *isochimenal* is the isotherm of the coldest months. All these means of temperature are calculated and reduced to the same altitude above the sea level; but it is not to be forgotten that the altitude has a great influence on these values.

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